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Each of the potential water-related problems is addressed in the context of the probable cumulative regional impact of a maturing, commercial oil shale industry and in terms of local impact resulting from the prototype operation initially planned on leased public lands. The possible effects of potential pollutants on ambient water quality and the resulting impact on aquatic life, public water supplies, livestock, irrigation agriculture, and selected industries are evaluated. Where sufficient data are available, attempts are made to relate historical, current, and projected water quality data to water quality criteria for various water uses.

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March 1979

SURFACE WATER QUALITY PARAMETERS FOR MONITORING OIL SHALE DEVELOPMENT

by

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FOREWORD

Protection of the environment requires effective regulatory actions which are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach which transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment

- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report assesses the potential local and regional impact of an oil shale industry on surface water resources within the Colorado River Basin, and recommends chemical, physical, and biological parameters which can be used to assess the environmental impact on surface water resources. Potential users of the information include federal, state, and local environmental and public health agencies as well as private organizations engaged in water quality monitoring and assessment. For further information contact the Water and Land Quality Branch, Monitoring Operations Division.

George B Morgan
George B. Morgan
Director
Environmental Monitoring and Support Laboratory
Las Vegas

PREFACE

The status of oil shale as an alternative domestic energy source has been in a state of flux since the inception of the prototype leasing program in 1971. Initially, four tracts of public land, of approximately 2,070 hectares each, two in Colorado and two in Utah, were leased to private industry for the purpose of commercial development of shale oil on a prototype scale, using various technologies and technology mixes. Original plans for development on all tracts involved surface or underground mining followed by surface processing of the oil shale and shale oil. In situ processing technology was still in the experimental stages when the federal lease program was initiated, and prospects for application of in situ technology on a commercial scale prior to 1980 seemed remote.

A number of factors have significantly altered the direction and rate of development of the industry. Spiraling developmental and production costs coupled with uncertain world market crude oil prices have purportedly dampened the economic incentive of many of the participating companies, and a number of original investors have withdrawn from the venture. The lease of the Utah tracts has been suspended and currently there are no firm plans for development in these tracts. Development in Colorado's Piceance Basin appears imminent but current plans are to use modified in situ processes on both the C-a and C-b tracts. Modified in situ technology requires some surface processing and/or stockpiling since about 20 percent of the shale must be mined out, processed, and disposed of or stockpiled at the surface before in situ retorting can occur.

Our consideration of the environmental problem addressed in this report was predicated on the assumption that surface processing would follow underground or aboveground mining rather than through utilization of modified in situ technology. Although surface retorting is not currently being considered as a primary processing technique for development on federally leased tracts C-a and C-b, it is likely that application of surface retorting technology will escalate throughout the oil shale area as the industry continues to develop. A federally sponsored surface retort is currently in operation at Anvil Points producing shale oil for large scale refining tests by the Office of Naval Research which is investigating the feasibility of converting shale oil to fuel for use in military vehicles. The Department of Energy (DOE) is apparently promoting continued development of surface retorting technology, and is requesting 1979 funding for emergency leasing of a full-scale surface module. The Director of the Department's Laramie Energy Research Center (LERC) feels that by the 1990's surface techniques will be stronger than in situ techniques and many surface facilities will be in operation (Maugh 1977).

ABSTRACT

This report develops and recommends prioritized listings of chemical, physical, and biological parameters which can be used to assess the environmental impact of oil shale development on surface water resources. The derivation of the list and the prioritization of the parameters are based on a review of current information regarding potential pollutants and the severity of the possible impact on ambient water quality with respect to water use criteria.

Each of the potential water-related problems is addressed in the context of the probable cumulative regional impact of a maturing, commercial oil shale industry and in terms of local impact resulting from the prototype operation initially planned on leased public lands. The possible effects of potential pollutants on ambient water quality and the resulting impact on aquatic life, public water supplies, livestock, irrigation agriculture, and selected industries are evaluated. Where sufficient data are available, attempts are made to relate historical, current, and projected water quality data to water quality criteria for various water uses.

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1. INTRODUCTION

Development of an oil shale industry on the semiarid western slope of the Rocky Mountains poses a threat to the water resources of the Colorado River Basin. A mature oil shale industry (1-million-barrels-per-day)[a] and associated industrial and urban development would consume large quantities of high quality water and require the disposal and displacement of large volumes of wastewater and saline ground water. In addition, contamination of surface waters from point and nonpoint sources would be an ever present threat during developmental and operational stages. This report develops and recommends prioritized listings of chemical, physical, and biological parameters which can be used for monitoring and assessing the environmental impact of oil shale development on surface water resources.

High quality freshwater is a scarce resource throughout much of the western United States. Any activity which potentially degrades or consumes large quantities of freshwater must therefore be continually scrutinized and rigorously controlled to ensure that the impact on water resources is minimized.

The total impact of a mature oil shale industry on water resources cannot be quantitatively assessed until long after production on a commercial scale has begun. Many unknowns confront the investigator who attempts to develop predictive capabilities to forecast the nature and magnitude of such effects. Accurate prediction requires a thorough knowledge of the hydrological and geological regimens of the area and an understanding of the transport routes and fates of pollutants mobilized by man's activities and released to subsurface and surface water. Although the oil shale area has been studied for many years, most efforts have been directed towards delineating the areas of high quality, oil-bearing shale. Until recently, the water resources of much of the area had only been superficially studied. Consequently, the geology of the area is fairly well described, but hydrological data, particularly subsurface water data in some sectors are conspicuously lacking.

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[a] To aid readability, the units (acre-ft) and (ft^3/s) expressions (English) are maintained in the text followed by the metric equivalents [in cubic meters (m^3) and cubic meters per second (m^3/s), respectively] in parentheses. The unit "barrel" is neither a metric nor an English measurement but is an industrial term. One barrel equals 42 gallons or 158.87 liters of oil. We believe presenting the data in this manner renders the information more meaningful to personnel involved in all disciplines. All other units of measure are expressed in accordance with the modernized metric system. Totally converted tables using metric units appear in Appendix A.

The Federal prototype oil shale leasing program is designated to provide for the assessment of the environmental impact of development and operation of small-scale commercial industries using various mining and processing technologies. [See USDI (1973) vol. III, ch. V, for discussion of mitigating measures and lease provisions.] Four tracts of public lands of approximately 2,073 hectares, two in Colorado and two in Utah (Figures 1 and 2), were leased by industry from the Federal government for purposes of oil shale development. Extraction and processing would occur under rigorous guidelines as stipulated by the conditions of the lease in an effort to minimize environmental impact. If development proves to be environmentally acceptable and economically profitable, a mature commercial industry may evolve from the Federal prototype leasing program.

Provisions of the lease require self-monitoring by the industry as specified by the Area Oil Shale Mining Supervisor of the U.S. Geological Survey prior to, during, and subsequent to developmental activities (USDI 1973, vol. III, p. V-42). Baseline environmental quality data collection systems were in operation for approximately two years.

The Water and Land Quality Branch, Monitoring Operations Division, of the U.S. Environmental Protection Agency's Environmental Monitoring and Support Laboratory, Las Vegas, Nevada, has been conducting a program designed to test and evaluate water quality monitoring techniques in the oil shale area of Colorado and Utah as part of its nonpoint source pollution assessment and monitoring procedures development program. The Las Vegas laboratory's experimental monitoring program was operated and tested primarily on the reach of the White River adjacent to the Utah tracts, with minimal testing in the upstream reaches in Colorado. Since water quality data compiled by the industry and the U.S. Geological Survey were available for comparative purposes, an excellent opportunity was presented for testing and assessing monitoring techniques and procedures.

An initial step in monitoring design is the identification of those biological, chemical, and physical parameters most appropriate for measurement as a mechanism for quantitating the impact of development of the industry on surface water resources. The derivation of the list of recommended parameters presented in this report is based on a review of current information regarding potential pollutants from oil shale development and their possible impact on water quality and the biota.

Each of the potential water-related problems is addressed in the context of the probably cumulative regional impact of a maturing, commercial oil shale industry and in terms of local impact resulting from the prototype operation initially planned on leased public lands. The possible effects of potential pollutants on ambient water quality and the resulting impact on aquatic life, public water supplies, livestock, irrigation agriculture, and selected industries are evaluated. Where sufficient data are available, attempts are made to relate historical, current, and projected water quality data to water quality criteria for the various water use categories.

The water quality criteria data were extracted primarily from an EPA-funded document entitle "Water Quality Criteria - 1972" produced by the

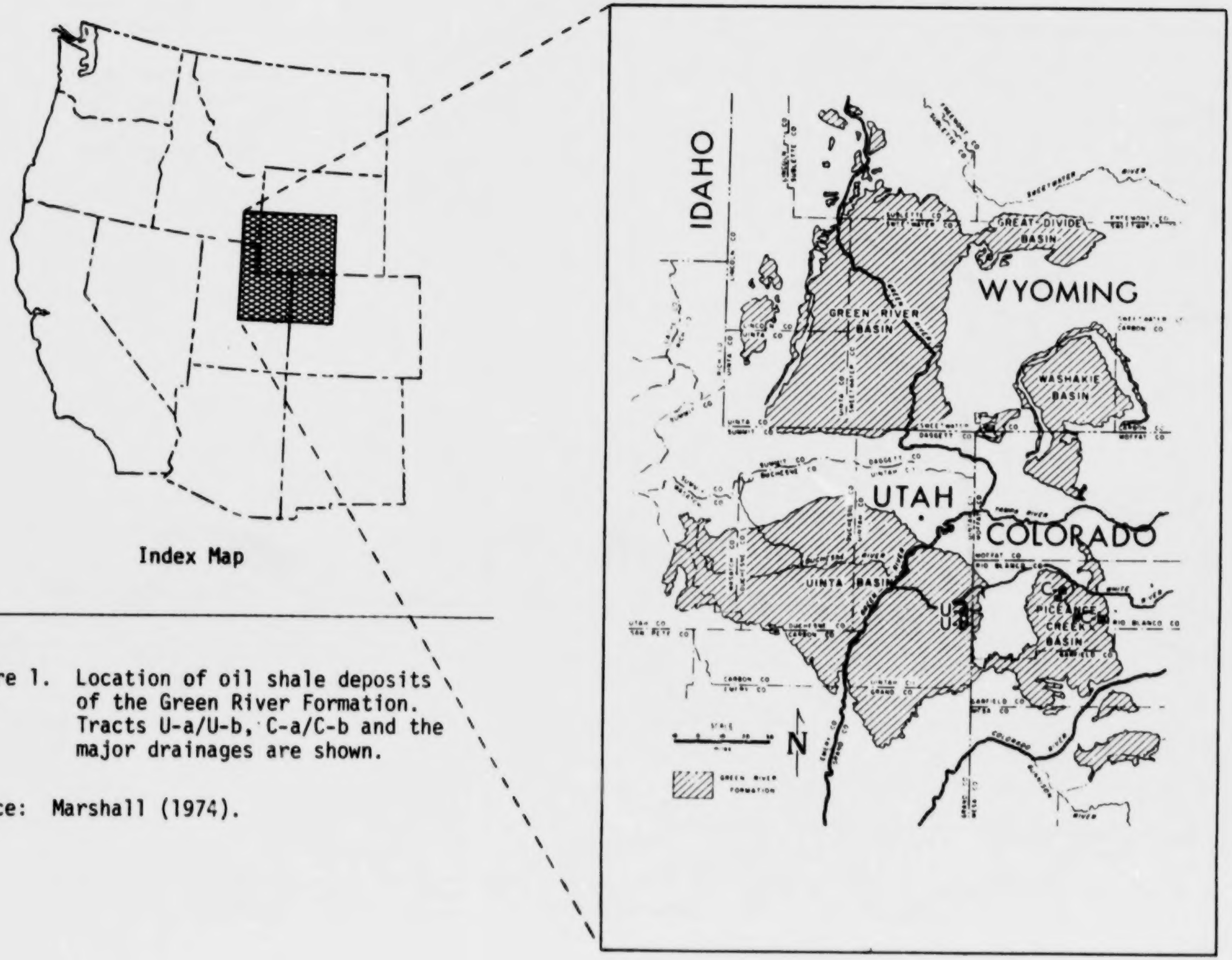

Figure 1. Location of oil shale deposits of the Green River Formation. Tracts U-a/U-b, C-a/C-b and the major drainages are shown.

Source: Marshall (1974).

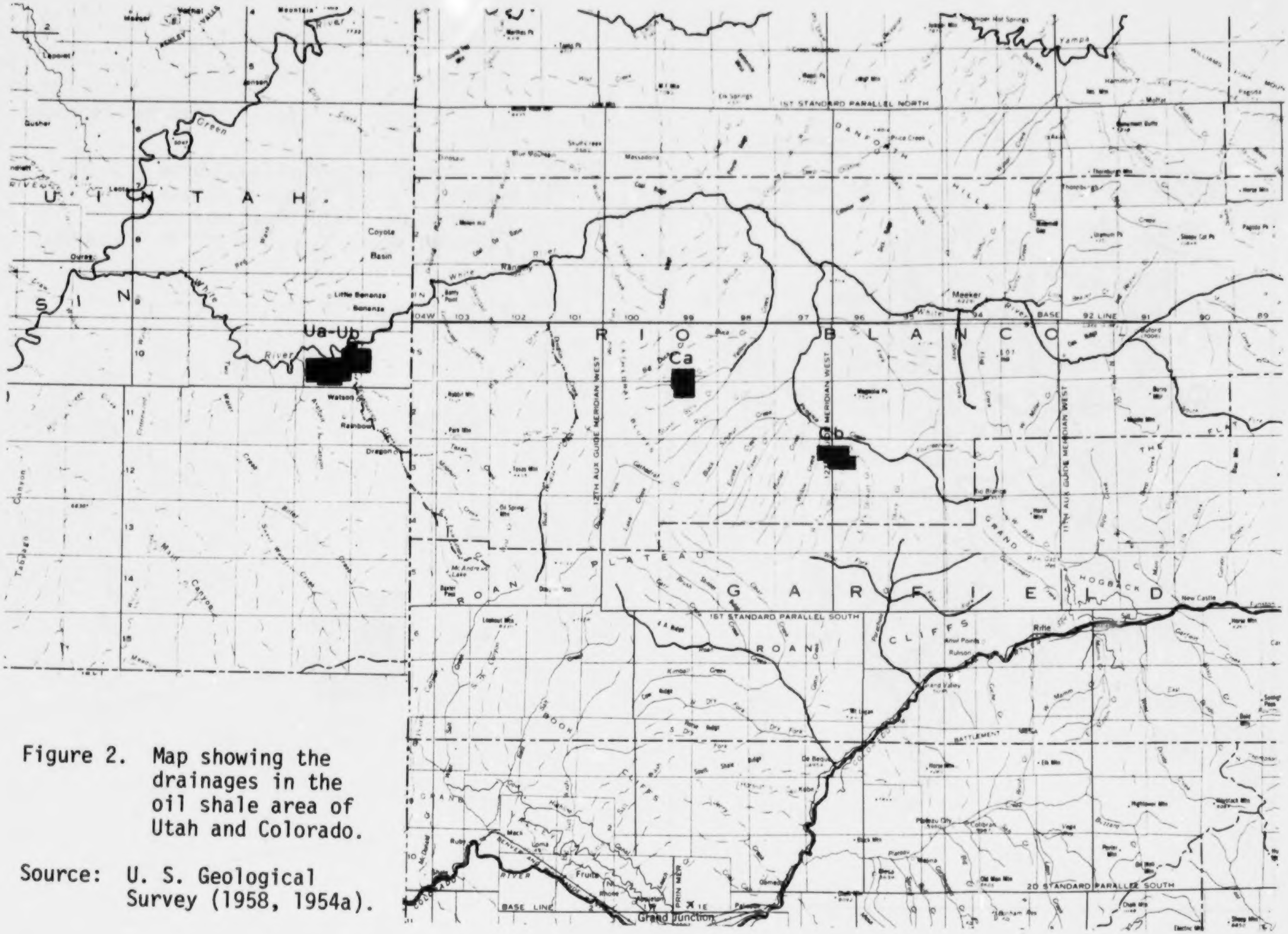

Figure 2. Map showing the drainages in the oil shale area of Utah and Colorado.

Source: U. S. Geological Survey (1958, 1954a).

National Academy of Sciences (NAS 1973). The Agency has recently released a preliminary draft of its own water quality criteria document which differs somewhat from the NAS (1973) version. The NAS document, however, was the most current published water quality criteria document available through the Agency at the time this report was prepared.

The parameter list presented here is tentative and subject to revision as circumstances dictate. Possibly, additional parameters will be added, some existing parameters deleted or assigned different priorities as information gained from field and laboratory testing warrants. The parameter list is not all-inclusive and should not be interpreted as meeting Agency water quality sampling or monitoring requirements for oil shale development, but it is envisioned that such a parameter list may evolve from the program.

Absence of a particular parameter from the list should not be construed to mean that the parameter in question is of no significance and can be ignored. Insufficient information is currently available to assess the pollution potential or level of hazard of a number of constituents (e.g., trace organics) which may be subject to release and mobilization as a result of industrial and associated urban development. The report makes no attempt to recommend sampling frequencies, techniques, detection levels, or locations at this stage in the program. These monitoring aspects will be addressed in later reports.

2. CONCLUSIONS AND RECOMMENDATIONS

The establishment of a commercial oil shale industry on the western slope of the Rocky Mountains poses a threat to the water resources of the Colorado River Basin, both on a Regional and local scale. The nature and magnitude of the impact to water resources as a consequence of oil shale development cannot be predicted with certainty. A number of extractive and processing technologies are currently approaching commercial developmental stages and several small-scale facilities have been periodically operated on a prototype scale for several years. However, none has been applied in this country in a full-scale commercial venture.

The potential impact to water resources varies greatly with the different mining and retorting methods utilized and with the size of the operations. Water use requirements, with respect to both quality and quantity, are highly variable depending upon the technology applied. Similarly, volumes of solid wastes and wastewaters generated (including highly mineralized groundwater from mine dewatering operations) and subsequent disposal requirements are also primarily dependent upon the technologies utilized and volumes of raw materials processed.

The Federal prototype leasing program was designed in part to provide for the assessment of the environmental impact of small-scale commercial oil shale industries utilizing a mix of technologies at various rates of operation. To effectively assess the impact of such development on water resources and beneficial water uses, thorough baseline characterization of water quality and quantity during pre-developmental stages is a fundamental prerequisite. An obvious additional requirement for the detection and quantification of physical, chemical and biological changes and for relating such changes to causative factors is the establishment and operation of an effective monitoring system.

An initial step in the design of monitoring systems is the identification of those parameters most appropriate for incorporation into a comprehensive monitoring network. This is an extremely critical aspect of monitoring design for new industries such as oil shale, since the impact on beneficial water uses could be substantial.

This report presents a prioritized list of chemical, physical and biological parameters recommended for monitoring surface waters potentially impacted by oil shale developmental activities. Parameters recommended include those substances which in themselves are potential pollutants and are measurable directly, as well as those indicator parameters whose measurements provide an indirect measure of environmental disturbance or pollution or are required for the interpretation of other water quality data.

Physical and chemical parameters recommended for monitoring are categorized by priority "A", "B" or "C", and the specific form most appropriate for monitoring is identified. Priority "A" physical and chemical parameters are recommended for intensive monitoring because: (1) very slight changes in their ambient levels would render water unacceptable for specified designated beneficial water uses; (2) changes in ambient levels would be indicative of potentially deleterious changes in water quality characteristics; or (3) data are required for the interpretation of other water quality data. Priority "B" physical and chemical parameters are recommended for routine monitoring of a lower intensity than that for those parameters in the priority "A" category because slight changes in ambient levels can be tolerated without exceeding established limits for designated beneficial water uses. The measurement of parameters in this category should be in addition to those in the priority "A" category but at reduced frequencies. Priority "C" physical and chemical parameters are recommended for periodic monitoring in addition to those in the "A" and "B" categories to characterize water quality with respect to ambient levels of particular constituents and designated beneficial water uses.

An increase in salinity is one of the major potential impacts resulting from developmental activities, through both salt loading and salt concentrating effects. To assess the rate and impact of increased salinity levels, total dissolved solids, conductivity, hardness and the principal cations and anions (sodium, potassium, magnesium, sulfates and chloride) are recognized as highly significant parameters (priority "A" parameters) and are recommended for intensive monitoring. Calcium and carbonates are priority "B" salinity-related parameters recommended for routine monitoring.

Among the trace elements aluminum, boron, copper, fluoride, iron, lead, magnesium, manganese, mercury, molybdenum, nickel and zinc are recommended as priority "A" category parameters. The potential for release and mobilization of these elements as a result of development is high, and very slight changes in ambient levels could render water unacceptable for a number of beneficial water uses. Such elements as arsenic, barium, beryllium, cadmium, chromium, cobalt, lithium, selenium, and silver are recommended as priority "B" parameters. While these elements are potential pollutants, ambient levels are relatively low, and slight increases in levels would not interfere with beneficial water uses. Antimony, bismuth and bromine are examples of priority "C" parameters which require periodic monitoring.

A number of miscellaneous toxic substances are identified as potential pollutants, but only cyanide, phenols, and organochlorine pesticides are recommended as priority "A" parameters. Organophosphorus pesticides, polychlorinated biphenyls and phthalate esters are recommended as priority "B" parameters, and the LAS detergent builders and certain miscellaneous pesticides are in the priority "C" category.

Macronutrients which promote excessive growth of aquatic plants include various forms of nitrogen and phosphorus. Since eutrophication is not expected to be a major problem as a consequence of development of an oil shale industry, most nutrient forms fall in the priority "B" or "C" categories. However, because slight increases in nitrate nitrogen and ammonia could render water unacceptable for certain designated beneficial uses, these nitrogen forms are recommended as priority "A" parameters.

None of the radionuclides are expected to increase to the level where beneficial water uses will be impaired as a result of oil shale development. All radionuclides are recommended as priority "B" or "C" parameters.

Since potential for release of oils is relatively high, intensive monitoring of visible oils on the surface and emulsified oils is recommended (priority "A"). Hexane extractable substances in streambed sediments are recommended for periodic monitoring (priority "C" parameter).

Temperature is a critical measurement for two reasons: (1) increases may occur as a result of developmental activities to the point where aquatic life may be adversely affected, and (2) temperature affects the chemical and biological activity of a number of parameters. Consequently, water temperature is a priority "A" parameter recommended for intensive monitoring.

Suspended sediment levels can be expected to increase as a result of developmental activities. Both suspended sediments (solids) and turbidity (an indication of suspended sediment levels in the water column) are recommended as priority "A" parameters.

Ambient dissolved oxygen (DO) levels may be altered by the introduction of oxygen demanding substances to the point where aquatic life may be adversely affected. In addition, water uses for industrial purposes and irrigation of croplands may be impaired by waters with high chemical oxygen demand (COD) levels. Both DO and COD are recommended as priority "A" parameters.

Since Colorado River system waters are well-buffered, few changes are expected in ambient pH levels as a result of developmental activities. However, since the possibility of disturbance to the equilibrium of the bicarbonate/carbon dioxide/carbonate system exists, for example as a result of acid rain-out, all alkalinity-related parameters are recommended as priority "B" parameters.

One of the most crucial parameters for interpreting water quality data is volume of flow or discharge (priority "A"). Since many perturbations in water quality are flow rated, flow measurements and discharge computations must be an integral component of surface water quality monitoring design.

Biological parameters recommended for monitoring are categorized by priority "A" or "B". Priority "A" biological parameters are recommended for routine monitoring in any basic water quality monitoring program designed to assess the environmental impact of oil shale and associated development on aquatic ecosystems. Priority "B" biological parameters are not recommended for monitoring unless a specific problem is encountered or suspected in a particular environment.

Examples of priority "A" biological parameters include counts and identification, biomass determinations and community composition and diversity measurements of macrobenthic and periphyton communities.

Counts and identification of phytoplankton, determination of growth rates of fish, and species identification of macrophytes are examples of additional measurements recommended if specific problems are encountered (priority "B" parameters).

The prioritized list of parameters recommended for monitoring must be viewed as tentative and subject to revision as additional information becomes available. No attempt was made to address the many trace organic constituents which have recently been identified as potential pollutants with carcinogenic, mutagenic or teratogenic effects on the biota and man. Additional research is needed to further identify these various organic compounds, their potential for release to the environment and effects of exposure to receptors including man.

3. WATER REQUIREMENTS AND AVAILABILITY

USE REQUIREMENTS

Assuming extraction of shale oil proves to be economically advantageous and environmentally acceptable on a prototype scale, the single factor which will eventually limit the size of the industry will undoubtedly be water availability. Although dewatering of mines and certain processing operations produce water, the quantity required for the total operation of a mature industry exceeds that produced.

Nearly all phases of the industry consume water (Table 1). The greatest consumptive use requirements are for disposal of processed shale and oil upgrading (USDI 1973, vol. I, p. III-37). Associated urban growth and ancillary industrial development will also consume substantial quantities of water. Projected water demand estimates for processing requirements and urban development vary considerably depending on the rate of shale oil production and the mining techniques utilized (Table 2). The most likely water use requirements for a 1-million-barrel-per-day industry range between 121,000 and 189,000 acre-ft (1.49×10^8 to $2.33 \times 10^8 m^3$) per year. The projected water needs for mining, crushing, retorting and upgrading are fairly well defined, but the actual requirements for spent shale disposal and revegetation have not been firmly established for large-scale operations and could deviate substantially from current estimates.

Water quality requirements vary with intended uses. High quality water which is low in total dissolved solids (TDS) is necessary for retorting, upgrading, power generation, revegetation, sanitary use, and associated urban development. Mining and crushing operations and disposal of spent shale can be accomplished with low quality water such as that produced by oil upgrading and retorting.

SUPPLY

Surface Water

Colorado's Piceance Creek Basin, the area of the richest oil shale deposits, is drained to the north by Sheep, Piceance, Yellow, Spring, and Douglas Creeks, all of which flow into the White River. Parachute and Roan Creeks drain the southern part of the oil shale area into the Colorado River (Figures 1 and 2). Streamflow in the Basin is highly variable with most streams sustaining substantial flow only during periods of snowmelt or after

TABLE 1. CONTINGENT WATER CONSUMPTION FORECASTS FOR A 1-MILLION-BARREL-PER-DAY SHALE OIL INDUSTRY

Requirements	Range of Water Consumption (acre-ft/yr)		
	Lower Range	Most Likely	Upper Range
Processing:			
Mining and crushing	6,000	6,000- 8,000	8,000
Retorting	9,000	9,000- 12,000	12,000
Shale oil upgrading	17,000-21,000	29,000- 44,000	44,000
Processed shale disposal	24,000	47,000- 70,000	84,000
Power	10,000	15,000- 23,000	37,000- 45,000
Revegetation	0	0- 12,000	18,000
Sanitary use	1,000	1,000- 1,000	1,000
Subtotals	67,000-71,000	107,000-170,000	204,000-212,000
Associated Urban:			
Domestic use	9,000-11,000	13,000- 17,000	17,000
Domestic power	0	1,000- 2,000	2,000
Subtotals	9,000-11,000	14,000- 19,000	19,000
TOTALS	76,000-82,000	121,000-189,000	223,000-231,000
Ancillary Development:			
Nahcolite/dawsonite	...	...	32,000- 64,000
GRAND TOTALS	76,000-82,000	121,000-189,000	255,000-295,000

Source: Modified from USDI (1973, vol. I, p. III-44).

TABLE 2. RANGES OF WATER USE FOR VARIOUS RATES AND METHODS OF SHALE OIL PRODUCTION (acre-ft/yr)

Requirements	Shale Oil Production (barrels per day)/Method of Production				
	50,000/ Underground Mine	100,000/ Surface Mine	50,000/ In Situ Mining	400,000/ Technology Mix	1,000,000/ Technology Mix
Processing:					
Mining and crushing	370- 510	730- 1,020	...	2,600- 3,600	6,000- 8,000
Retorting	580- 730	1,170- 1,460	...	4,100- 5,100	9,000- 12,000
Shale oil upgrading	1,460- 2,190	2,920- 4,380	1,460-2,220	11,700-17,500	29,000- 44,000
Processed shale disposal	2,900- 4,400	5,840- 8,750	...	20,400-30,900	47,000- 70,000
Power	730- 1,020	1,460- 2,040	730-1,820	5,800- 9,200	15,000- 23,000
Revegetation	0- 700	0- 700	0- 700	0- 4,900	0- 12,000
Sanitary use	20- 50	30- 70	20- 40	200- 300	1,000- 1,000
Subtotals	6,060- 9,600	12,150-18,420	2,210-4,780	44,800-71,500	107,000-170,000
Associated Urban:					
Domestic use	670- 910	1,140- 1,530	720- 840	5,400- 6,900	13,000- 17,000
Domestic power	70- 90	110- 150	70- 80	500- 600	1,000- 2,000
Subtotals	740- 1,000	1,250- 1,680	790- 920	5,900- 7,500	14,000- 19,000
GRAND TOTALS	6,800-10,600	13,400-20,100	3,000-5,700	50,700-79,000	121,000-189,000
MEAN VALUES	8,700	16,800	4,400	65,000	155,000

Source: Modified from USDI (1973, vol. I, p. III-34).

heavy rains (Table 3). Piceance Creek, which has the largest drainage area of any tributary in the Basin, has a mean annual discharge of only 17 cubic feet per second (ft^3/s) (0.48 m^3/s) at the White River confluence.

The White River also exhibits wide seasonal and annual variability in flow as indicated by discharge records at Ignatio Station near the U-a/U-b tracts (Figures 3 and 4). As these data indicate, the streamflow of the river is far too irregular to be used as a reliable water source for industrial use in the natural flow state. Water could be available for purchase from proposed public and private projects on the White and Yampa Rivers (USDI 1973, vol. I, p. II-133). Proposed dams (Yellow Jacket and Rio Blanco or Sweetbriar projects) could yield as much as 165,000 acre-ft ($2.04 \times 10^8 m^3$) when, and if, completed (USDI 1973, vol. I, p. II-133).

Water from the Colorado River and its tributaries is available through the U.S. Bureau of Land Management at a cost of 10 to 40 dollars per acre-ft (1,233.5 m^3) (USDI 1973, vol. I, p. II-133). The purchaser would have to assume the substantial costs of transporting the water from the main channel or releasing reservoir to the point of use. Impoundments where water is currently available are Ruedi and Green Mountain Reservoirs. In theory, the Bureau of Land Management could make up to 200,000 acre-ft ($2.47 \times 10^8 m^3$) of water available for use in the Piceance area from existing and proposed projects including the purchase of existing senior water rights (USDI 1973, vol. I, p. II-133).

Possible sources of surface waters for an oil shale industry in Utah's Uinta Basin include the Green, White, and Yampa Rivers (Figure 1). The Green River with a mean flow of 4,307 ft^3/s (121.9 m^3/s) is the main flowing body of water in the area, traversing the richest oil shale deposits in a northeast to southwest direction. The White River, with a mean flow of 703 ft^3/s (19.9 m^3/s), flows into the Green from the east within the bounds of the Uinta-Ouray Indian Reservation. The Yampa, also a westward flowing stream, has its confluence with the Green within the boundaries of the Dinosaur National Monument north of the major oil shale deposits.

Approximately 107,000 acre-ft ($1.32 \times 10^8 m^3$) of water annually are potentially available from the Green, White, and Yampa Rivers for development of oil shale in the Uinta Basin (USDI 1973, vol. I, p. II-26). Utilization of water from the White and Yampa would require construction of dams and reservoirs. A proposal to dam the White River in the vicinity of the U-a/U-b tracts is currently being considered. The Green River is already impounded at Flaming Gorge Reservoir.

Under existing agreements with Mexico, the States involved, and private interests, the surface water potentially available for oil shale development has been calculated at 341,000 acre-ft ($4.21 \times 10^8 m^3$). The distribution of the water is as follows (USDI 1973, vol. I, p. II-27):

TABLE 3. SUMMARY OF STREAMFLOW RECORDS OF STREAMS DRAINING THE COLORADO OIL SHALE AREA

Streamflow station	Period of record (mo/yr)	Drainage area (mi^2)	Average discharge (ft^3/s)	Extremes of discharge (ft^3/s)	
				Maximum	Minimum daily
West Fork Parachute Creek near Grand Valley	10/57-9/62	48	4.37	147	0
Parachute Creek near Grand Valley	10/48-9/54 10/64-9/67	144	17.7	738	0
Parachute Creek at Grand Valley	4/21-9/27 10/48-9/54	200	30.3	912	0
Roan Creek at Simmons Ranch	6/35-9/35 4/36-10/36 3/37-9/37	79	--	142	0
Roan Creek above Clear Creek	10/62-9/67	151	14.8	800	1.0
Roan Creek near DeBeque	4/21-9/26 10/62-9/67	321	40.0	1220	3.2
Piceance Creek at Rio Blanco	10/52-9/57	9	1.40	23	0.1
Piceance Creek near Rio Blanco	10/40-9/43	153	20.3	430	0.1
Piceance Creek below Ryan Gulch	10/64-9/67	485	12.5	400	0.8
Piceance Creek at White River	10/64-9/66	629	17.0	550	0.9
Yellow Creek near White River	10/64-9/66	258	1.37	1060	0

Source: Modified from Coffin, et al. (1971).

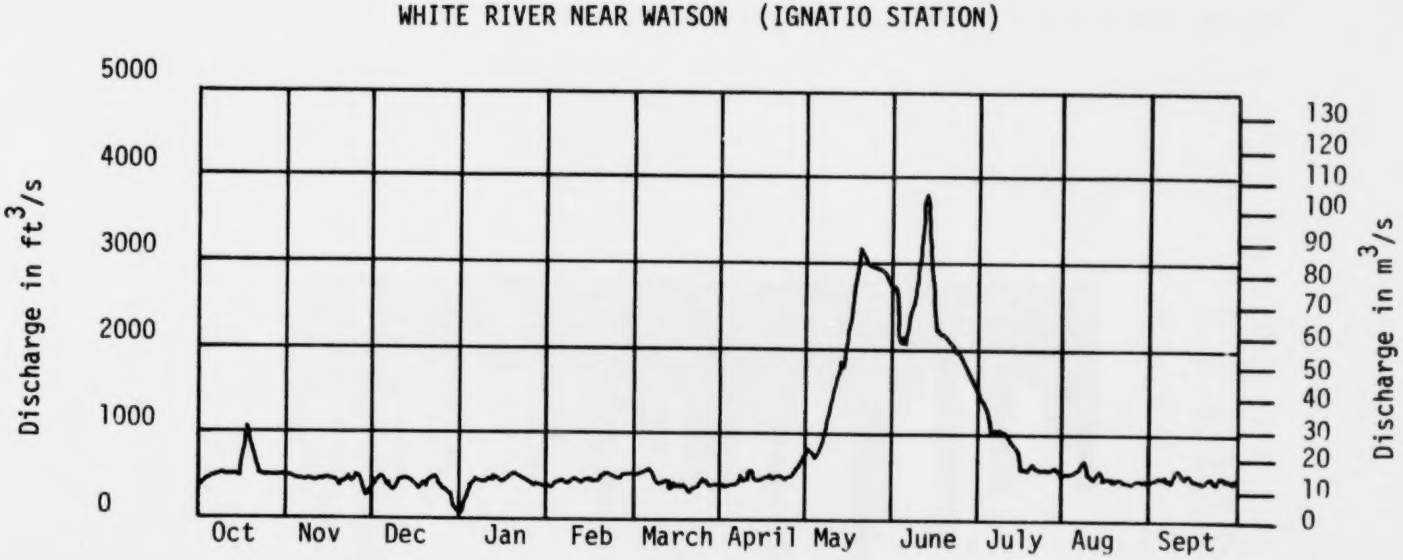

Figure 3. Seasonal runoff patterns of the White River at Ignatio Station near Watson in water year 1970.

Source: USGS (1973)

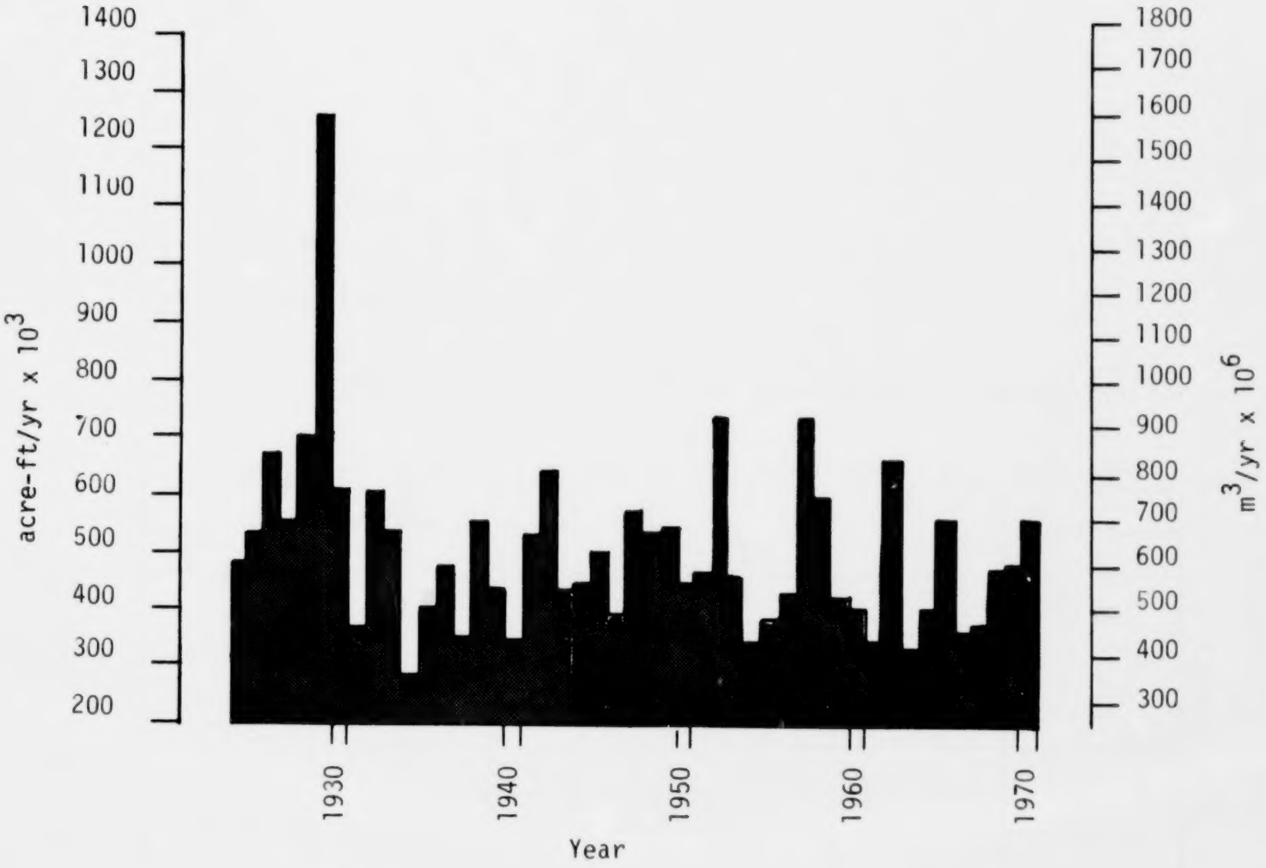

Figure 4. Variability of discharge of the White River at Ignatio Station near Watson, Utah, years 1924-70.

Source: USGS (1954b, 1973).

State	acre-ft	m^3
Colorado	167,000	2.06×10^8
Utah	107,000	1.32×10^8
Wyoming	67,000	8.26×10^7
Totals	341,000	4.21×10^8

Subsurface Water

In general, ground water supplies in the oil shale areas of Utah are meager. The best possibilities for significant quantities of ground water lie in the Piceance Creek Basin.

The Uinta Basin in Utah is a good example of an oil shale area in which the ground water in storage is thought to be of little or no use to large-scale industrial development (USDI 1973, vol. I, p. II-230). The Green River Formation is the principal aquifer and yields as much as 29.5 ft^3 (0.834 m^3) per minute to wells; however, yields that large cannot be expected throughout the Formation (USDI 1973, vol. I, p. II-56).

The Uinta Formation overlying the Green River Formation yields as much as 30 ft^3 (0.85 m^3) per minute from springs (USDI 1973, vol, I, p. II-56). Although the potential yield from wells could be as large, the overall volume of water in storage would be considerably less than that in the Piceance Creek Basin (USDI 1973, vol. I, p. II-230).

More detailed information concerning ground water availability and quality in the Uinta Basin can be found in the U-a/U-b final environmental baseline report for the White River shale project, Voorheis-Trindle-Nelson of Colorado 1977 **(environmental baseline data collection contractor).**

USDI (1973, vol. I, pp. II-48 through II-55) identified three sources of ground water in the Piceance Creek Basin: (1) alluvium, (2) upper aquifer, and (3) lower aquifer or "lower leached-zone" (Figure 5). The water in the overlying alluvium, due to the limited volume, is of little significance for industrial purposes.

The upper aquifer comprises the lower portion of the Uinta Formation [formerly known as the Evacuation Creek Member of the Green River Formation, nomenclature revised by Cashion and Donnell (1974)] and the part of the Parachute Creek Member which lies above the Mahogany zone. The upper aquifer is a relatively good aquifer where water has a TDS content generally less than 1,000 mg/liter.

The upper aquifer and the lower aquifer are separated by the Mahogany zone. The Mahogany zone is less permeable than either aquifer and generally acts as a barrier between them. However, water is occasionally transmitted through the Mahogany zone by fractures which permit communication.

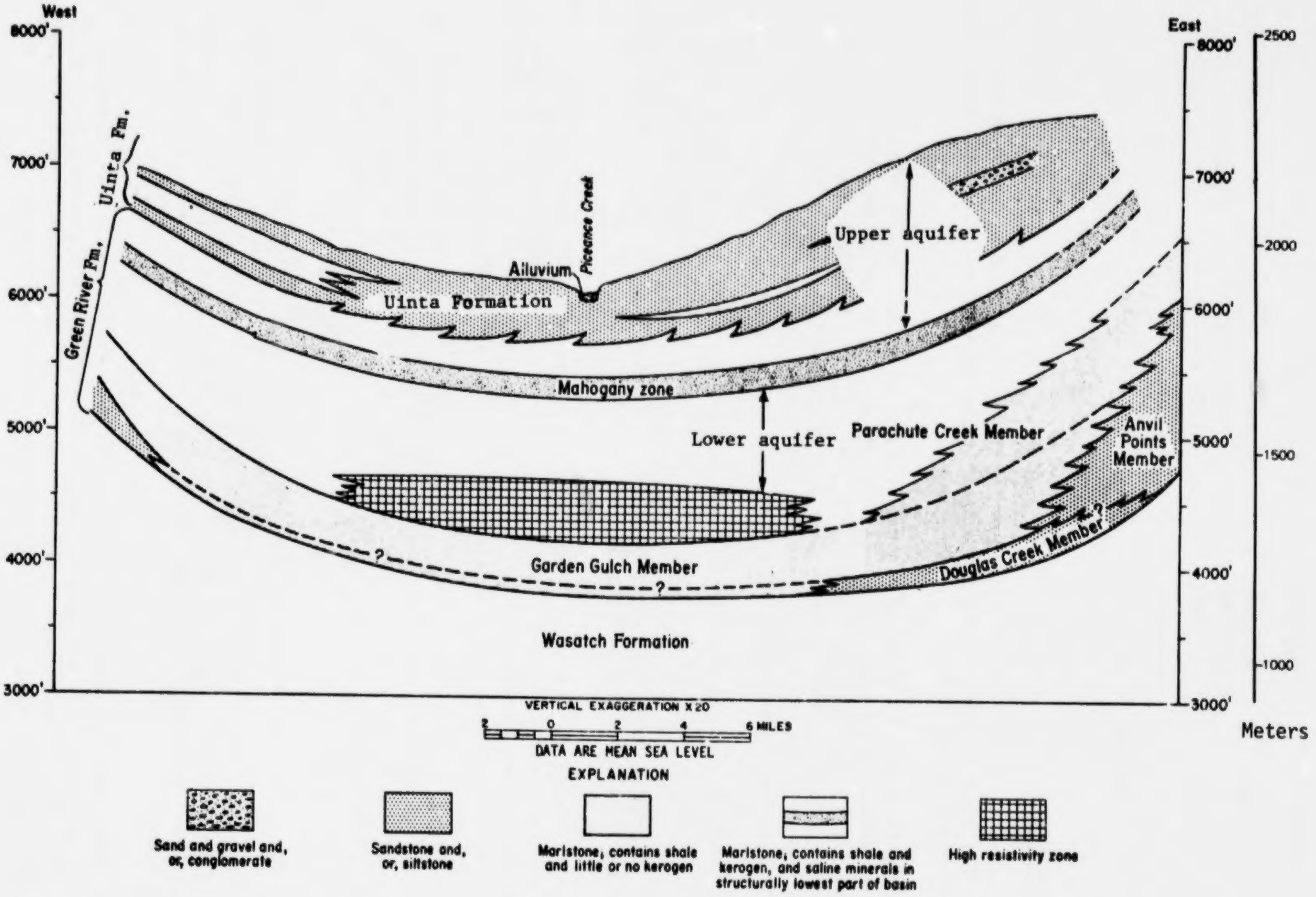

Figure 5. Diagrammatic section across the Piceance Creek Basin, Colorado.

Source: Modified from Coffin, et al. (1968).

The lower aquifer, the area below the Mahogany zone, consists of the remaining portion of the Parachute Creek Member of the Green River Formation and is the most extensive and permeable aquifer in the Basin. The TDS concentrations increase with depth from the edges toward the center of the Basin with concentrations ranging from 2,000 to 63,000 mg/liter (Coffin, et al. 1968).

Extensive work attempting to define the ground water quality and quantity in the Piceance Creek Basin has been done by the lessees of the C-a and C-b Federally leased tracts. This information can be found in:

1) The final environmental baseline report for tract C-a and vicinity. May, 1977, prepared by Rio Blanco Oil Shale Project, 2 volumes.

2) Oil shale tract C-b final environmental baseline program final report, November 1974 - October 1976, prepared by C-b Shale Oil Venture, 5 volumes.

By-Product Water

Mining of oil shale from the Mahogany zone of the Piceance Creek Basin must be preceded or accompanied by the dewatering of the enclosing aquifers. It is not known what the initial pumping rates will be. Based on hydrological data, the present best estimate is a maximum of 30 ft^3/s (0.849 m^3/s) for surface development and 40 ft^3/s (1.13 m^3/s) for underground development or an overall requirement of 22,000 to 29,000 acre-ft (2.71×10^7 to $3.5 \times 10^7 m^3$) per year (USDI 1973, vol. I, p. III-53). The estimated amount of water required and the quality and quantity of water produced by underground and surface mines over a 30-year period were summarized in USDI (1973) (Table 4). Of the overall waters to be removed from the subsurface, 30 percent are estimated to be fresh and 70 percent saline to briny (USDI 1973, vol. I, p. III-57).

The oil shale retorting process itself is a producer of water, yielding from 7 to 28 liters per metric ton (2 to 10 gallons per ton) of shale processed. The amount of water produced in this manner by a 1-million-barrel-per-day industry based on an average yield of 25 gallons of oil per ton of shale would range from 10.3 to 51.5 acre-ft (12.7×10^3 to $63.5 \times 10^3 m^3$). When this amount is compared to the overall needs of a mature industry, the water produced is insignificant.

TABLE 4. WATER REQUIRED AND PRODUCED BY TWO SINGLE MINES FOR A PROJECTED 30-YEAR PERIOD OF SHALE OIL PRODUCTION

Requirements[a]	Shale Oil Production (barrels per day)/Type of Mine							
	50,000/Underground Mine				100,000/Surface Mine			
	Water Requirements[b]	Water Produced[c]	Excess Water	Diverted Water	Water Requirements[b]	Water Produced[d]	Excess Water	Diverted Water
Processing:								
High quality water	75-127	175	60-100	0-12	151-234	175	25-46	22- 58
Low quality water	88-133	373	240-285	...	178-266	373	107-195	...
Subtotals	163-260	548	300-385	0-12	329-500	548	132-241	22- 58
Associated Urban:								
High quality water	20- 27	...	...	20-27	34- 45	...	...	34- 45
TOTALS	183-287	548	300-385	20-39	363-545	548	132-241	56-103

[a] In thousands of acre-ft.

[b] This would represent the maximum diverted surface water requirements should no water be available from processing or from the mines.

[c] Assumes a maximum pumping rate of 40 ft^3/s declining to 18 ft^3/s in the 30th year.

[d] Assumes a maximum pumping rate of 30 ft^3/s declining to 18 ft^3/s in the 30th year.

Source: Modified from USDI (1973, vol. I p. III-60).

4. POTENTIAL IMPACT OF THE OIL SHALE INDUSTRY

SALINITY

Sources

Increasing salinity is the major water quality problem throughout much of the Colorado River Basin. Salinity levels have been steadily increasing throughout the lower Basin as a result of two basic processes: salt loading (i.e., increasing the total mineral burden by adding salts to the river) and salt concentrating (i.e., the selective removal of high quality water thereby concentrating the total salt burden in a smaller volume). Salt loading results from both natural conditions and man-induced causes; salt concentrating results when water is lost through consumptive uses, transpiration, or evaporation.

Although adequate information is lacking to accurately identify all contributing sources of salinity to the Colorado River, studies conducted over the past 20 years have identified the major sources of increasing salinity from the headwaters to the Gulf of California (USEPA 1971). The relative effects of salt loading and salt concentrating factors on the salinity of the river at Hoover Dam for the period 1942-61 were estimated by USEPA (1971) (Table 5). Nearly two-thirds of the average annual salt load and one-half of the concentration at Hoover Dam during this period were attributed to natural causes (USEPA 1971). Of the portion attributable to natural sources, about 82 percent was from diffuse (nonpoint) sources and about 18 percent from point sources (USEPA 1971). Irrigation agriculture, which increases salinity both through salt loading and salt concentrating, was estimated to contribute 33 percent of the total annual salt load and 37 percent of the salinity concentration at Hoover Dam during this period (Table 5).

Although industrial and municipal discharges accounted for only about one percent of the salt load and salinity concentration at Hoover Dam during this period (Table 5), a mature oil shale industry and related industrial and urban development could, over the long term, increase the salinity at Hoover Dam through both salt concentrating and salt loading processes. Salt concentrating effects would occur as relatively high quality surface waters are withdrawn for consumptive uses and as a result of evaporation from storage reservoirs. Assuming substantial amounts of ground water and process water are available for use as discussed previously (USDI 1973, vol I, p. III-75), it is not anticipated that salt concentrating effects will add to the salinity detriment of the Colorado River until many years after development is instituted. Salt loading could occur as a result of landscape disturbances resulting from construction activities and from the actual mining operation.

TABLE 5. CAUSES OF SALINITY CHANGES AT HOOVER DAM (1942-61 PERIOD OF RECORD ADJUSTED TO 1960 CONDITIONS)

Factor	Salt Load[a] (millions of tons)	Percent of Salt Load	Salinity Concentration Ascribable to Each Source (mg/liter)	Percent Salinity Concentration Ascribable to Each Source
Natural diffuse sources	5.41	50.4	275	39
Natural point sources	1.28	11.9	59	8
Irrigated agriculture	3.54	33.0	253	37
Salt loading	(3.54)	(33.0)	(178)	(26)
Salt concentrating	(0)	(0)	(75)	(11)
Municipal and industrial	(0.15)	1.4	10	1
Exports out of the Basin	-0.04	-0.4	20	3
Evaporation and phreatophytes	0.00	0.0	80	12
Storage release from Hoover	0.39	3.7	0	0
Totals	10.73	100.0	697	100

[a] Computed annual values for balancing based upon the net drawdown over the 1942-61 period.

Source: Modified from USEPA (1971).

Additional loading could result from leaching of spent shale disposal piles or by-products storage piles; release of saline mine waters; ground water disturbances caused by reinjection of excess waters; and municipal and industrial waste discharges.

Construction of roadways and utility corridors, removal of overburden, and the actual mining operations would enhance weathering and erosion of exposed materials thereby increasing the potential for mineral release to surface waters directly and via subsurface waters.

Leachates from spent shale are a potential source of salt loading to surface water owing to the proposed disposal methods and the physical and chemical characteristics of spent shale (USDI 1973, vol. I, p. III-77). Disposal of spent shale will be accomplished by creating disposal sites and possibly by backfilling mined-out areas. Even if backfilling is practiced, some above ground shale disposal will be necessary since the volume of compacted spent shale is greater than its inplace volume due to void spaces in the mass of crushed and retorted materials (USDI 1973, vol. I, p. I-22). The mineral composition of spent shale varies somewhat depending on the retorting process used due to differences in peak temperatures reached in the various retorts. The Union Oil Company (UOC) retort reaches a peak temperature of approximately 540° C causing almost complete decomposition of carbonates and other temperature-sensitive materials (USDI 1973, vol. I, p. I-24). The Oil Shale Company (TOSCO) retort, which operates at a temperature of 482° C, causes very little mineral decomposition (USDI 1973, vol. I, p. I-24). Regardless of the process used, spent shale materials are represented primarily as oxides of the various minerals present in raw shales (Tables 6 and 7), many of which are highly water soluble (USDI 1973, vol. I, pp. I-24,25). Ward et al. (1971) investigated the water pollution potential of spent shale residues from various retorts. Analyses of water after intimate contact with spent shale from the TOSCO and UOC retorts revealed high concentrations of sodium, calcium, and magnesium in the form of sulfates. Leaching tests demonstrated that soluble salts are readily leached from spent shale columns, consequently a definite potential exists for high concentrations of the major ions (Na^+, Ca^{2+}, Mg^{2+}, and SO_4^{2-}) in the runoff from spent oil shale residues (Ward, et al. 1971).

The mechanical instability of processed shale and the susceptibility of shale piles to leaching of salts pose serious potential hazards to the water quality of streams in the area. Although there has been no actual experience with disposal of spent shale on a large scale, some potential problems can be anticipated. The possibility of disposal-pile failure, i.e., the "falling in" of the face of the pile with a subsequent increase in erosion and salt loading to local streams and the expected impact on water quality, has been assessed in a hypothetical situation (USDI 1973, vol. I, pp. III-81-89). In this example, it was estimated that leaching of a 283.3-hectare spent shale pile during an intensive 6-hour rainstorm of 1.27 centimeters per hour would increase the total salt load of the receiving stream (Piceance Creek) by 2,177 to 4,989 metric tons.

Weathering and leaching of spent shale piles will occur over long periods of time, but the rate of release of minerals to surface waters cannot be

TABLE 6. MINERAL COMPOSITION OF SPENT SHALE ASH

Component	Composition expressed as oxide weight (percent of ash)
Silica dioxide (SiO_2)	42.3
Iron oxide (Fe_2O_3)	4.5
Aluminum oxide (Al_2O_3)	13.0
Calcium oxide (CaO)	23.1
Magnesium oxide (MgO)	9.9
Sulfur trioxide (SO_3)	1.8
Sodium oxide (Na_2O)	3.1
Potassium oxide (K_2O)	2.3
Total	100.0

Source: Modified from Matzick, et al. (1966), as compiled by USDI (1973, vol. I, p. I-25).

TABLE 7. TYPICAL COMPOSITION OF RAW OIL SHALE SECTIONS AVERAGING 25 GALLONS OF OIL PER TON FROM THE MAHOGANY ZONE OF COLORADO AND UTAH

	Percent by weight	
ORGANIC MATTER	13.8	
Carbon (C)		80.5
Hydrogen (H)		10.3
Nitrogen (N)		2.4
Sulfur (S)		1.0
Oxygen (O)		5.8
Total		100.0
MINERAL MATTER	86.2	
Carbonates, principally dolomite		48.0
Feldspars		21.0
Quartz		13.0
Clays, principally illite		13.0
Analcite		4.0
Pyrite		1.0
Total		100.0
TOTAL	100.0	

Source: Modified from U.S. Bureau of Mines (1970), compiled by USDI (1973, vol. I, p. I-10).

predicted (USDI 1973, vol. I, p. III-89). Even though attempts will be made to stabilize the piles with natural soil and vegetative cover, erosion and leaching of dissolved solids will undoubtedly occur, particularly during the periods of active disposal and shale pile buildup.

Raw wastewater produced by retorting oil shale contains a variety of constituents, thus presenting a wastewater disposal or treatment problem. If the untreated water is used to moisten shale piles as has been proposed, the mineral components may be physically or chemically trapped within the shale pile temporarily, but the potential for leachates eventually moving through the pile would seemingly be increased. A possible alternative is to treat the wastewater for subsequent use within the plant, thus partially offsetting the requirements for water from outside sources.

In the Piceance Basin, disposal of excess mine waters poses a potential problem which may be intensified as the oil shale industry matures. During the early stages of operation, excess water is expected to be of high quality and may be released directly to local streams, but through time the excess water will increase in salinity, and discharge to local streams may not be permitted (USDI 1973, vol. I, p. III-61). It may be necessary during initial development to store excess or poor quality ground water in impoundments and during later stages of development to reinject the excess water in aquifers (USDI 1973, vol. I, p. III-62). Both methods of disposal could potentially result in release of saline waters into streams; the first through failure of a dike impounding saline waters; and the second through upward movement of poor quality ground water and eventual discharge to surface waterways (USDI 1973, vol. I, pp. III-77-94).

Ranges of dissolved constituents in ground waters in the lower Uinta Formation and Parachute Creek Member of the Green River Formation differ considerably (Figure 6, Table 8). In general, water quality decreases with depth, with the poorest quality water occurring in the deeper portions of the Parachute Creek Member of the Green River Formation.

Municipal and industrial developments could cause additional salinity problems. As the population of the area expands, increased amounts of salts may enter surface waters via municipal and industrial discharges thereby increasing the total mineral burden in localized areas. Since the nature and extent of urban and associated industrial growth cannot be predicted with certainty, the extent to which such growth will compound the salinity problem is unknown.

Ambient Levels

As a means of characterizing ambient water quality in those surface waters potentially subject to impact as a result of oil shale development, historical data for salinity related parameters were compiled, summarized, and tabulated for selected U.S. Geological Survey (USGS) water quality monitoring stations on the White, Green and Colorado Rivers (Figure 7). Ranges and mean values for specific ions, total dissolved residues and specific conductance summarized for water years 1964-65 and 1968-69 (USGS 1970, 1974) characterize

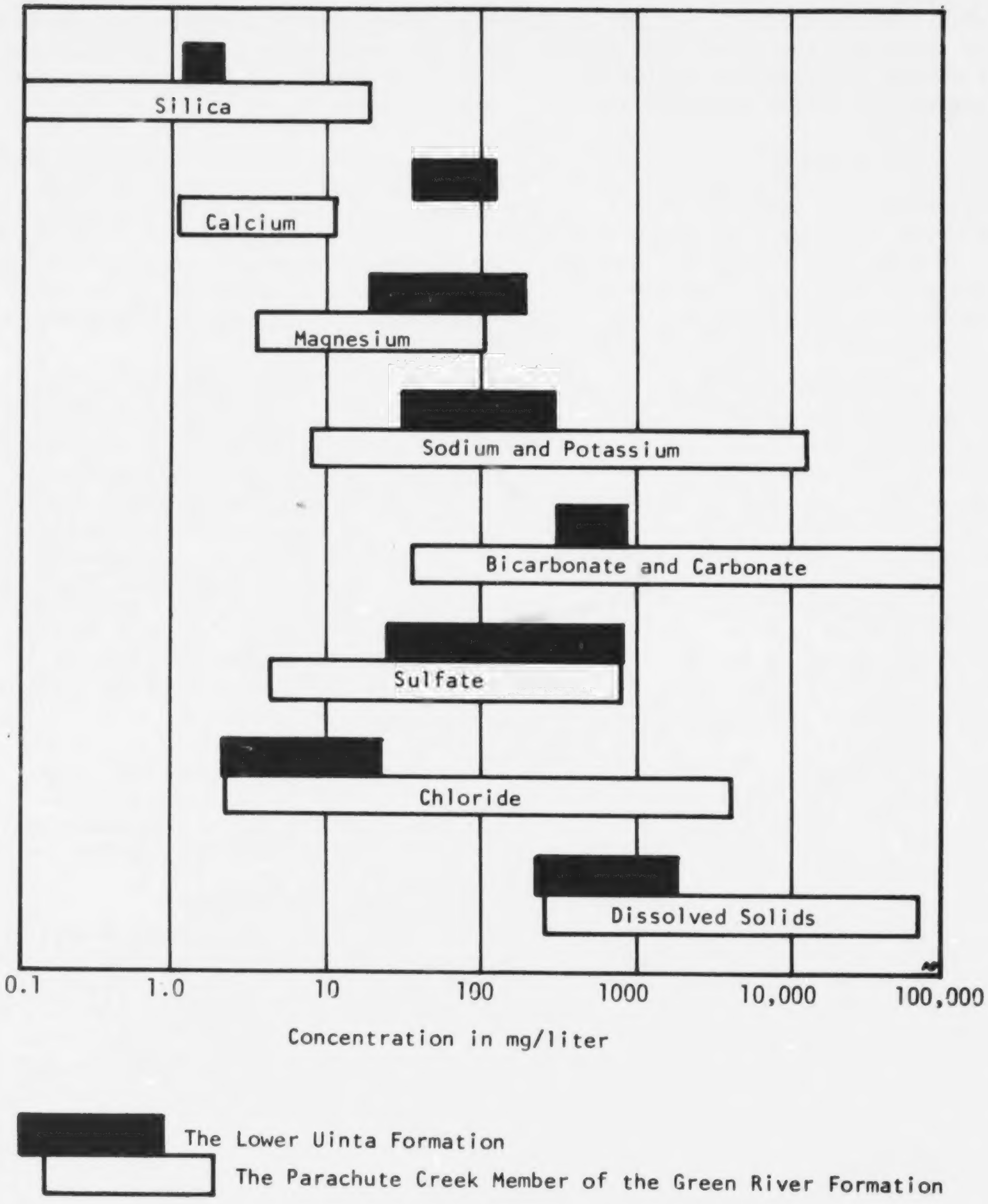

Figure 6. Range of water quality in the lower Uinta Formation (formerly the Evacuation Creek Member of the Green River Formation) and in the Parachute Creek Member of the Green River Formation.

Source: USDI (1973).

TABLE 8. SUMMARY OF GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS IN THE PICEANCE CREEK BASIN

Alluvium, 0-140 feet thick; Holocene and Pleistocene in age:	
Physical Character --	Sand, gravel and clay partly fill major valleys as much as 140 feet; generally less than one-half-mile wide. Beds of clay may be as thick as 70 feet; generally thickest near the center of valleys. Sand and gravel contain stringers of clay near mouths of small tributaries to major streams.
Water Quality --	Near the headwaters of the major streams, dissolved-solids concentrations range from 250 to 700 mg/liter. Dominant ions in the water are generally calcium, magnesium, and bicarbonate. In most of the area, dissolved solids range from 700 to as much as 25,000 mg/liter. Above 3,000 mg/liter the dominant ions are sodium and bicarbonate.
Hydrologic Character --	Water is under artesian pressure where sand and gravel are overlain by beds of clay. Reported yields as much as 1,500 gpm[a]. Well yields will decrease with time because valleys are narrow and the valley walls act as relatively impermeable boundaries. Transmissivity ranges from 20,000 to 150,000 gpd[b] per ft. The storage coefficient averages 0.20.
Uinta Formation, 0-1,250 feet thick; Eocene in age:	
Physical Character --	Intertonguing and gradational beds of sandstone, siltstone and marlstone: contains pyroclastic rocks and few conglomerate lenses. Forms surface rock over most of the area; thins appreciably westward.
Water Quality --	Water ranges from 250 to 1,800 mg/liter dissolved-solids.

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[a] Gallons per minute.

[b] Gallons per day.

(Continued)

TABLE 8. SUMMARY OF GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS IN THE PICEANCE CREEK BASIN (Continued)

Unita Formation, 0-1,250 feet thick; Eocene in age: (Continued)	
Hydrologic Character --	Beds of sandstone are predominantly fine grained and have low permeability. Water moves primarily through fractures. The part of the Formation higher than valley floors is mostly drained. Reported to yield as much as 100 gpm where tested in the north-central part of the basin. Formation has not been thoroughly tested, and larger yields may be possible.
Green River Formation:	
Parachute Creek Member, 500-1,800 feet thick; Eocene in age:	
Physical Character --	Kerogenaceous dolomitic marlstone (oil shale) and shale; contains thin pyroclastic beds, fractured to depths of at least 1,800 feet. Abundant saline minerals in deeper part of the basin. The member can be divided into three zones which can be correlated throughout the basin by use of geophysical logs: (1) high resistivity, (2) low resistivity or leached, and (3) Mahogany (oldest to youngest).
Water Quality --	Water ranges in dissolved-solids content from 250 to about 63,000 mg/liter. Below 500 mg/liter, calcium is the dominant cation: Above 500 mg/liter, sodium is generally dominant. Bicarbonate is generally the dominant anion regardless of concentration. Flouride ranges from 0.0 to 54 mg/liter.
Hydrologic Character --	High resistivity zone and Mahogany zone are relatively impermeable. The leached zone (middle unit) contains water in solution openings and is under sufficient artesian pressure to cause flowing wells. Transmissivity ranges from less than 3,000 gpd per ft. in the margins of the basin to 20,000 gpd per ft. in the center of the basin. Estimated yields as much as 1,000 gpm. Total water in storage in leached zone 2.5 million acre-ft, or more.

(Continued)

TABLE 8. SUMMARY OF GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS IN THE PICEANCE CREEK BASIN (Continued)

Green River Formation: (Continued)

Garden Gulch Member, 0-900 feet thick; Eocene in age:

Physical Character --	Papery and flaky marlstone and shale; contains some beds of oil shale and, locally, thin beds of sandstone.
Water Quality --	One water analysis indicates dissolved-solids concentration of 12,000 mg/liter.
Hydrologic Character --	Relatively impermeable and probably contains few fractures. Prevents downward movement of water. In the Parachute and Roan Creeks drainages, springs are found along contact with overlying rocks. Not known to yield water to wells.

Douglas Creek Member, 0-800 feet thick: Eocene in age:

Physical Character --	Sandstone, shale and limestone; contains oolites and ostracods.
Water Quality --	The few analytical results indicate that dissolved-solids content ranges from 3,000 to 12,000 mg/liter. Dominant ions are sodium and bicarbonate, or sodium and chloride.
Hydrologic Character --	Relatively low permeability and probably little fractured. Maximum yield is unknown, but probably less than 50 gpm.

Anvil Points Member, 0-1,870 feet thick; Eocene in age:

Physical Character --	Shale, sandstone, and marlstone grade within a short distance westward into the Douglas Creek, Garden Gulch, and lower part of the Parachute Creek Member. Beds of sandstone are fine grained.
Water Quality --	The principal ions in the water are generally magnesium and sulfate. The dissolved-solids content ranges from about 1,200 to 1,800 mg/liter.

(Continued)

TABLE 8. SUMMARY OF GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS IN THE PICEANCE CREEK BASIN (Continued)

Green River Formation: (Continued)	
Hydrologic Character --	Sandstone beds have low permeability. A few wells tapping sandstone beds yield less than 10 gpm. Springs issuing from fractures yield as much as 100 gpm.
Wasatch Formation, 300-5,000 feet thick; Eocene in age:	
Physical Character --	Clay, shale, lenticular sandstone; locally beds of conglomerate and limestone. Beds of clay and shale are the main constituents of the Formation. Contains gypsum.
Water Quality --	Gypsum contributes sulfate to both surface water and ground water supplies.
Hydrologic Character --	Beds of clay and shale are relatively impermeable. Beds of sandstone are slightly permeable. The Formation is not known to yield water to wells.

Source: Modified from Coffin et al. (1971).

those waters as to the TDS levels and identify the primary constituents contributing to the salt load at various sites (Tables 9 and 10).

Although TDS and specific conductance levels fluctuated widely at each site, a general trend of increasing mineral levels in a downstream progression is clearly evident. Inspection of the data for trends relative to individual constituents identifies calcium as the major cation in the upper basin with sodium the most abundant cation in the more saline downstream reaches. A similar pattern emerges relative to bicarbonates and sulfates. Mean bicarbonate concentrations remained relatively stable throughout the basin, but decreased downstream in relative contributions to total dissolved solids concentrations. Sulfates on the other hand increased both in mean absolute and relative abundance in a downstream progression, replacing bicarbonates as the dominant anion in the lower Colorado River. Chloride concentrations increased downstream also, as might be expected. Silica concentrations remained relatively constant throughout the basin. Carbonates in carbonate (CO_3^{2-}) form were not present in significant quantities in the surface waters. Carbonates in these waters are present primarily as bicarbonates (HCO_3^{1-}).

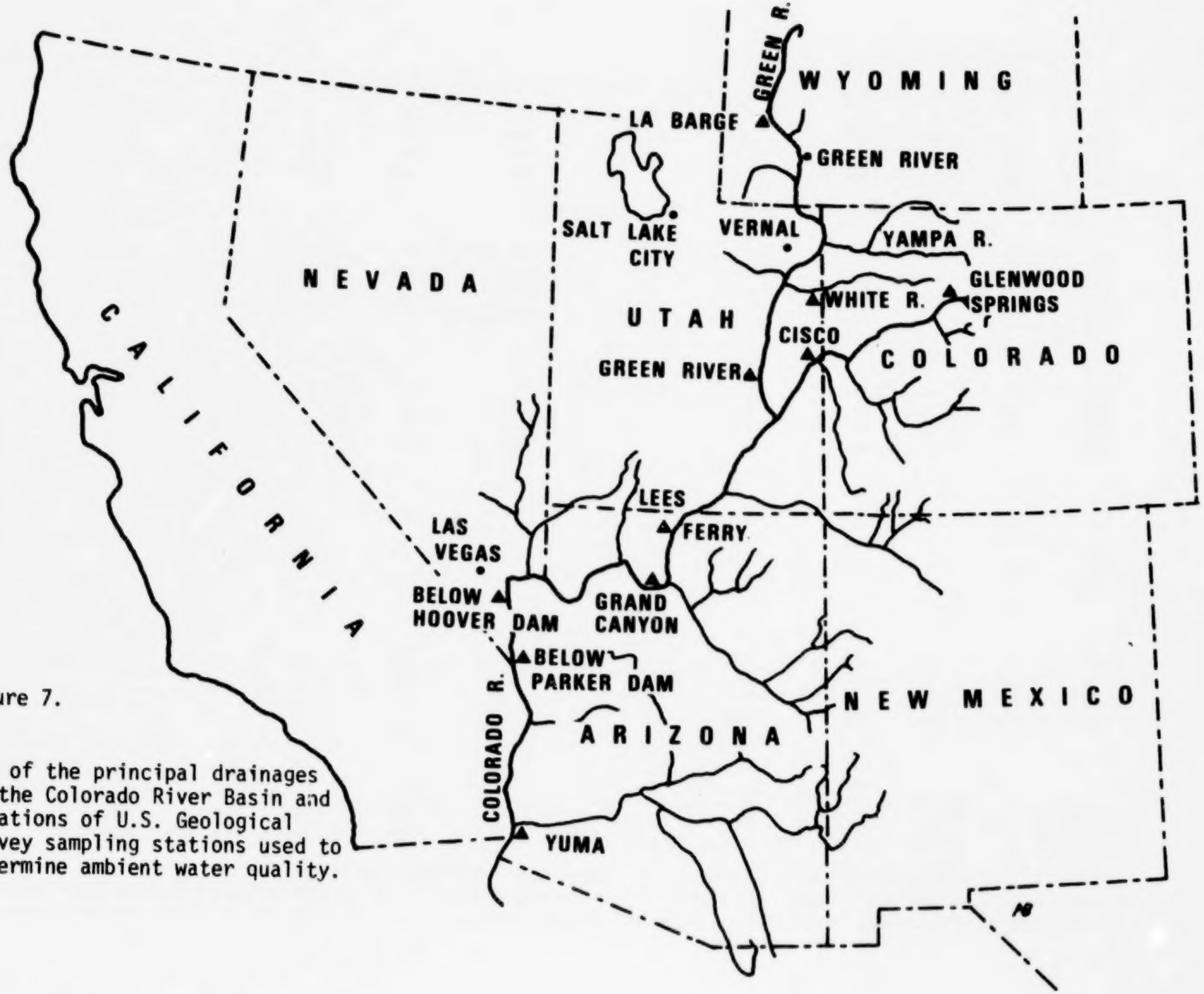

Figure 7.

Map of the principal drainages of the Colorado River Basin and locations of U.S. Geological Survey sampling stations used to determine ambient water quality.

TABLE 9. RANGES AND MEAN VALUES OF MAJOR SPECIFIC IONS, TOTAL DISSOLVED SUBSTANCES, AND SPECIFIC CONDUCTIVITY IN THE COLORADO RIVER BASIN SURFACE WATERS AT SELECTED LOCATIONS DURING 1964-65 (All values are based on analyses of filtered samples and are expressed in mg/liter except specific conductance which is expressed in μmhos/cm at 25° C.)

Location	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Bicarbonates (HCO_3)	Carbonates (CO_3)	Chlorides (Cl)	Sulfates (SO_4)	Silica (SiO_2)	TDS	Specific Conductance
Colorado River near Glenwood Springs, Colo.											
Maximum	61	14	2.7	148	240	0	200	154	10	666	1,100
Minimum	36	6.3	1.0	1.8	103	0	1.9	9.5	8.3	180	296
Mean	52	10.4	1.9	38	119	...	50	70	9.1	292	483
N[a]	3	3	3	24	24	24	24	24	3	24	24
Colorado River near Cisco, Utah											
Maximum	152	68	5.8	255	228	0	335	572	12	1,420	1,900
Minimum	46	7.1	1.8	21	112	0	17	79	9.9	256	404
Mean	72	23	4.7	65	151	...	65	191	11.2	530	791
N	31	31	4	31	31	31	31	31	4	31	31
Green River near La Barge, Wyo.											
Maximum	62	21	3.8	24	225	0	6.5	84	11	315	498
Minimum	25	8.1	0.8	6.1	113	0	1.5	15	5.8	125	211
Mean	36	12	1.4	10	147	...	2.6	34	8	191	303
N	25	25	25	25	25	25	25	25	25	25	25
White River near Watson, Utah											
Maximum	75	80	5.7	168	292	4	194	404	15	1,050	1,520
Minimum	65	15	1.7	22	148	0	14	63	8.6	250	403
Mean	70	35	2.8	63	202	0.12	48	143	13.1	457	707
N	5	5	5	34	34	24	34	34	5	34	34
Green River at Green River, Utah											
Maximum	123	46	3.2	127	248	10	53	441	12	934	1,280
Minimum	43	13	2.2	24	137	0	11	73	5.6	267	424
Mean	62	24	2.7	60	190	0.65	24	184	8.9	472	705
N	32	32	4	32	32	32	32	32	4	32	32

[a] N = Number of observations.

(Continued)

TABLE 9. RANGES AND MEAN VALUES OF MAJOR SPECIFIC IONS, TOTAL DISSOLVED SUBSTANCES, AND SPECIFIC CONDUCTIVITY IN THE COLORADO RIVER BASIN SURFACE WATERS AT SELECTED LOCATIONS DURING 1964-65 (All values are based on analyses of filtered samples and are expressed in mg/liter except specific conductance which is expressed in µmhos/cm at 25° C.) (Continued)

Location	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Bicarbonates (HCO_3)	Carbonates (CO_3)	Chlorides (Cl)	Sulfates (SO_4)	Silica (SiO_2)	TDS	Specific Conductance
Colorado River at Lees Ferry, Ariz.											
Maximum	103	30	5.5	103	180	0	76	329	12	754	1,120
Minimum	46	12	2.4	33	120	0	18	108	10	296	99[b]
Mean	81	24	4.1	79	161	...	57	255	11	609	735
N	18	18	4	18	18	18	18	18	4	18	18
Colorado River near Grand Canyon, Ariz.											
Maximum	111	30	5.1	120	216	0	110	326	13	853	1,240
Minimum	51	12	3.0	50	140	0	42	117	11	360	586
Mean	84	24	3.8	92	176	0	72	252	12	655	989
N	19	19	4	19	19	19	19	19	4	19	19
Colorado River below Hoover Dam, Ariz. and Nev.											
Maximum	107	31	5.6	119	166	0	112	354	11	845	1,240
Minimum	96	27	4.9	105	148	0	95	303	9	740	1,130
Mean	101.1	28.6	5.3	114.3	155.8	0	106.8	332.8	9.8	808.1	1,202.5
N	12	12	12	12	12	12	12	12	12	12	12
Colorado River below Parker Dam, Ariz. and Calif.											
Maximum	102	32	...	130	156	4	115	354	32	818	1,250
Minimum	87	28	...	104	144	0	97	298	10	705	1,120
Mean	93.5	30.3	...	113.7	151.1	0.3	104.9	324	15.5	758.9	1,180
N	14	14	0	14	14	14	14	14	14	14	14

[b] Questionable value.

Source: USGS (1970).

TABLE 10. RANGES AND MEAN VALUES OF MAJOR SPECIFIC IONS, TOTAL DISSOLVED SUBSTANCES, AND SPECIFIC CONDUCTIVITY IN THE COLORADO RIVER BASIN SURFACE WATERS AT SELECTED LOCATIONS DURING 1968-69 (All values are based on analyses of filtered samples and are expressed in mg/liter except specific conductance which is expressed in µmhos/cm at 25° C.)

Location	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Bicarbonates (HCO_3)	Carbonates (CO_3)	Chlorides (Cl)	Sulfates (SO_4)	Silica (SiO_2)	TDS	Specific Conductance
Colorado River near Glenwood Springs, Colo.											
Maximum	59	20	...	70	143	...	101	102	12	433	721
Minimum	33	5.8	...	13	99	...	18	31	7.3	182	279
Mean	46	11	...	36	120	...	51	68	9.3	297	479
N[c]	17	17	0	17	17	0	7	7	7	7	7
Colorado River near Cisco, Utah											
Maximum	160	64	222[a]	(*a*)	219	0	350	579	18	1,250	1,860
Minimum	51	14	28[a]	(*a*)	130	0	26	94	6.2	320	498
Mean	79	29	79[a]	(*a*)	166	0	73	240	10	631	924
N	47	47	6		47	47	47	47	47	47	47
Green River near La Barge, Wyo.											
Maximum	51	14	6.5	30	177	6	8.8	72	12	270[b]	467
Minimum	23	4.3	1.2	4.4	75	0	1.4	5.9	4.9	91[b]	171
Mean	35	8.6	1.7	9	125	1	4.0	33	6.8	161[b]	282
N	21	21	21	21	21	21	21	21	21	21	21
White River near Watson, Utah											
Maximum	71	37	4.0	80	298	25	154	450	15	1,020	1,420
Minimum	54	18	1.3	36	137	0	14	56	8.3	242	378
Mean	64	27	2.8	58	203	1	30	128	12.4	408	628
N	6	6	6	6	56	56	56	56	56	56	56

[a] Potassium value includes sodium value.

[b] Sum of constituents.

[c] N = Number of observations.

(Continued)

TABLE 10. RANGES AND MEAN VALUES OF MAJOR SPECIFIC IONS, TOTAL DISSOLVED SUBSTANCES, AND SPECIFIC CONDUCTIVITY IN THE COLORADO RIVER BASIN SURFACE WATERS AT SELECTED LOCATIONS DURING 1968-69 (All values are based on analyses of filtered samples and are expressed in mg/liter except specific conductance which is expressed in µmhos/cm at 25° C.) (Continued)

Location	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Bicarbonates (HCO_3)	Carbonates (CO_3)	Chlorides (Cl)	Sulfates (SO_4)	Silica (SiO_2)	TDS	Specific Conductance
Green River at Green River, Utah											
Maximum	145	43	112^{a}	(*a*)	238	0	42	505	11	994^{b}	1,270
Minimum	42	16	31^{a}	(*a*)	146	0	12	92	4.6	280^{b}	450
Mean	63	28	63^{a}	(*a*)	193	0	23	209	7.8	520^{b}	746
N	49	49	49		49	49	49	49	49	49	49
Colorado River at Lees Ferry, Ariz.											
Maximum	100	42	106^{a}	(*a*)	186	5	72	338	12	750^{b}	1,120
Minimum	66	21	69^{a}	(*a*)	144	0	43	206	9.8	493^{b}	783
Mean	81	29	85^{a}	(*a*)	169	1	57	274	11	711^{b}	954
N	17	17	12		17	17	17	17	14	16	17
Colorado River near Grand Canyon, Arizona.											
Maximum	97	36	140^{a}	(*a*)	196	0	108	332	13	812^{b}	1,180
Minimum	70	19	87^{a}	(*a*)	156	0	67	210	10	569^{b}	902
Mean	85	29	106^{a}	(*a*)	188	0	84	277	11.25	685^{b}	1,050
N	12	12	10		12	12	12	12	12	12	12
Colorado River below Hoover Dam, Ariz. and Nev.											
Maximum	94	36	118^{a}	(*a*)	174	0	104	327	9.7	751^{b}	1,150
Minimum	89	27	110^{a}	(*a*)	159	0	92	301	8.6	722^{b}	1,110
Mean	92	30	115^{a}	(*a*)	165	0	96	318	9.2	741^{b}	1,140
N	12	12	9		12	12	12	12	12	12	12

(Continued)

TABLE 10. RANGES AND MEAN VALUES OF MAJOR SPECIFIC IONS, TOTAL DISSOLVED SUBSTANCES, AND SPECIFIC CONDUCTIVITY IN THE COLORADO RIVER BASIN SURFACE WATERS AT SELECTED LOCATIONS DURING 1968-69 (All values are based on analyses of filtered samples and are expressed in mg/liter except specific conductance which is expressed in μmhos/cm at 25° C.) (Continued)

Location	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Bicarbonates (HCO_3)	Carbonates (CO_3)	Chlorides (Cl)	Sulfates (SO_4)	Silica (SiO_2)	TDS	Specific Conductance
Colorado River below Parker Dam, Ariz. and Calif.											
Maximum	96	32	130[a]	(*a*)	163	...	102	348	10	795[b]	1,200
Minimum	85	27	111[a]	(*a*)	152	...	89	293	8.2	695[b]	1,070
Mean	90	29	118[a]	(*a*)	159	...	98.6	317	9.2	742[b]	1,151
N	12	12	8		12	0	12	12	10	11	12

Source: USGS (1974).

Selected water quality data compiled by Voorheis-Trindel-Nelson (VTN) at four sites on the reach of the White River immediately adjacent to Federally leased tracts U-a/U-b were summarized to depict ambient water quality (Figure 8, Table 11). These data represent ranges and mean values reported during the period from late August 1974 to early May 1975. Inspection of these data reveals considerable variability between stations for some parameters even though the entire stream reach under investigation is only about 18 miles long. For example, maximum chloride values at site S-11 immediately downstream from the tract were nearly double the maximum values reported during this time period at any of the other sites. Maximum sodium values were 50 percent greater at the same station than maximum values reported at any of the other sites. As would be expected, correspondingly higher values were also reported for TDS and conductivity at this site.

Water quality data for Piceance Creek, which were compiled at three sites during the period from December 1970 to September 1973, indicate Piceance Creek waters are much more highly mineralized than White River waters (Tables 12 and 13).

Impact

As water becomes highly mineralized, its utility for industrial and agricultural purposes, public water supply, and as a medium for freshwater organisms is impaired. Present salinity concentrations in the lower Colorado River have reached the level where some impairment for industrial, agricultural, and municipal uses is occurring (USEPA 1971). As levels increase over 500 mg/liter, treatment costs soar for industrial and municipal water users, and irrigated agricultural crops characteristically undergo reductions in yield (NAS 1973). Highly mineralized water causes scaling and corroding of water pipes, boilers, and heaters, adding to increased maintenance and treatment costs for industrial and household users. As salt concentrations in irrigation waters increase, soils become more saline, thereby restricting the variety of crops which can be grown successfully (NAS 1973).

The effects of highly mineralized or saline water on aquatic life vary tremendously with the concentrations of specific ionic constituents. Although salinity in freshwater is defined as the total concentration of the ionic components (Reid 1961, Hutchinson 1957), the most conspicuous anionic substances which contribute to salinity in the Colorado River system are bicarbonates, sulfates, and chlorides. These substances combine with the metallic cations calcium, magnesium, sodium, and potassium to form ionizable salts. Silica may be present in several forms including complex ions, as colloidal silica or as sestonic mineral particles, but most silicates in inland waters are probably present as undisassociated silicic acid (Hutchinson 1957). The absolute and relative abundances of these materials are important factors regulating productivity of waters and influencing the structure of communities.

Water hardness, a term closely related to salinity, is governed chiefly by the presence of calcium and magnesium cations in waters. In general, the

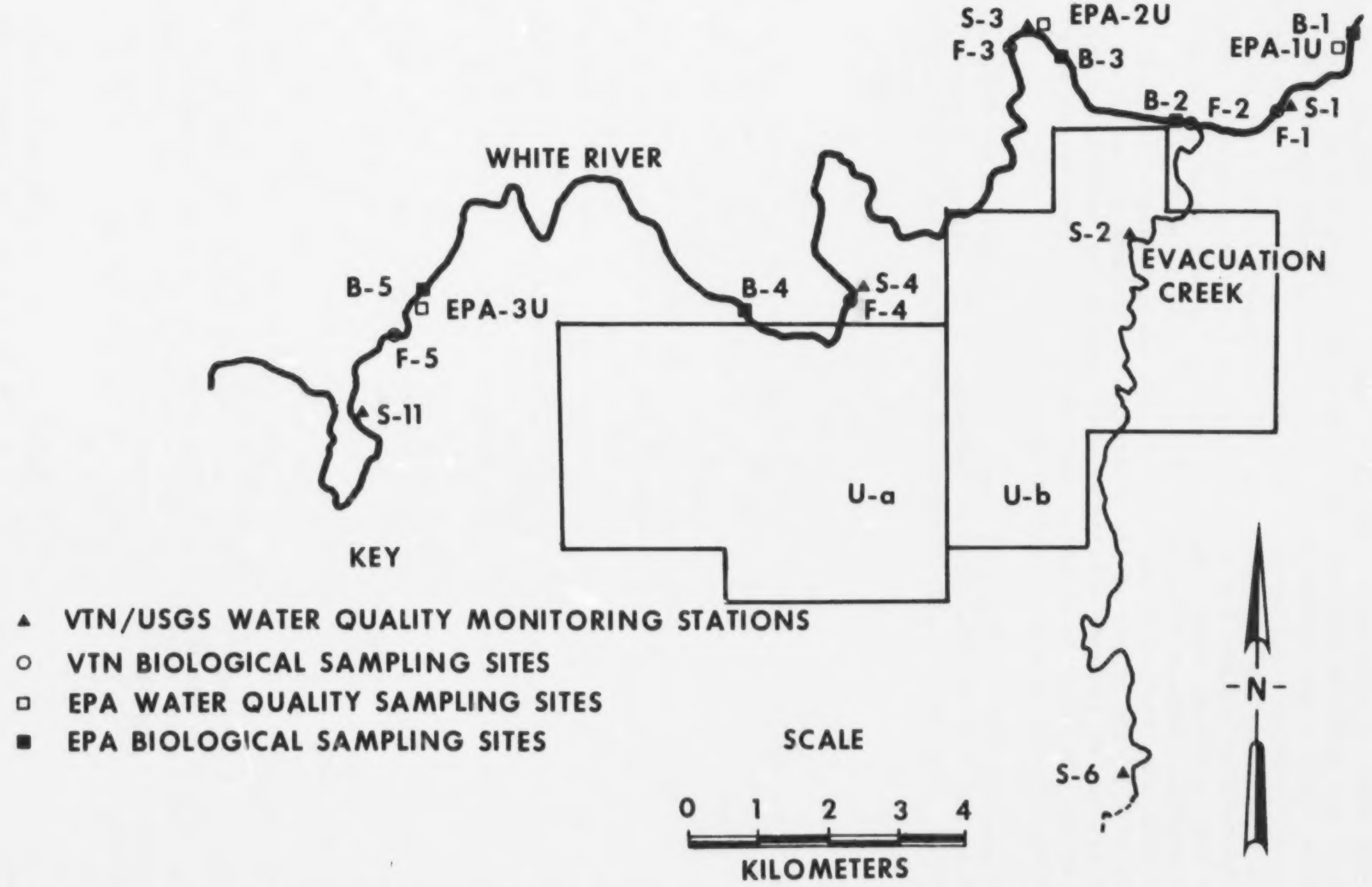
S-3
F-3
EPA-2U
B-3
B-1
EPA-1U
B-2
F-2
S-1
F-1
WHITE RIVER
S-2
EVACUATION CREEK
B-5
EPA-3U
F-5
B-4
S-4
F-4
S-11
U-a
U-b
KEY
▲ VTN/USGS WATER QUALITY MONITORING STATIONS
○ VTN BIOLOGICAL SAMPLING SITES
□ EPA WATER QUALITY SAMPLING SITES
■ EPA BIOLOGICAL SAMPLING SITES
SCALE
0 1 2 3 4
KILOMETERS
-N-
S-6

Figure 8. Surface water quality stations and biological sampling sites near Federal tracts U-a and U-b.

TABLE 11. SELECTED WATER QUALITY DATA NEAR TRACTS U-a/U-b, WHITE RIVER (All values are based on analyses of filtered samples and are expressed in mg/liter except for specific conductance which is expressed in µmhos/cm at 25° C.)

Location and Period of Record	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Bicarbonates (HCO_3)	Carbonates (CO_3)	Chlorides (Cl)	Sulfates (SO_4)	Silica (SiO_2)	TDS	Specific Conductance
Hell's Hole Canyon (S-1) August 1974- May 6, 1975											
Maximum	83	32	4.0	110	266	22	68	210	17	626	924
Minimum	61	23	0.9	57	193	0	32	160	11	489	480
Mean	70	27	2.4	74	240	1.7	42	178	13	543	829
N[a]	17	17	17	17	17	17	17	17	17	17	17
Ignatio (S-3) August 1974- May 5, 1975											
Maximum	120	39	2.8	120	288	3	79	250	17	676	1,020
Minimum	60	24	1.0	60	208	0	32	150	10	471	630
Mean	72	29	2.3	78	241	0.2	42	188	13	551	834
N	20	20	20	20	20	18	20	20	20	20	20
Southam Canyon (S-4) August 1974- May 6, 1975											
Maximum	82	36	5.0	130	295	3	120	260	17	717	1,100
Minimum	62	23	1.1	60	153	0	14	83	11	291	425
Mean	71	28	2.4	77	246	0	45	186	13	556	848
N	17	17	17	17	12	17	17	17	17	17	17
Asphalt Wash (S-11) August 1974- April 23, 1975											
Maximum	83	36	6.1	180	280	5	230	220	17	892	1,650
Minimum	61	24	1.1	54	223	0	34	160	11	464	425
Mean	72	29	2.4	80	248	0	54	188	14	579	892
N	16	16	16	16	16	16	15	16	16	16	16

[a] N = Number of Observations.

Source: VTN 4th quarterly report (1975), and unpublished USGS/VTN data.

TABLE 12. PICEANCE CREEK WATER QUALITY DATA DECEMBER 1970 TO DECEMBER 1972 (All values are based on analyses of filtered samples and are expressed in mg/liter.)

Location	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Bicarbonates (HCO_3)	Carbonates (CO_3)	Chlorides (Cl)	Sulfates (SO_4)	Silica (SiO_2)	TDS[a]
USGS #09306200, Station 102										
Maximum	89	110	4.8	310	933	0	25	550	21	1,550
Minimum	41	21	2.4	66	258	0	10	110	11	392
Mean	77	83	3.5	177	657	0	18	385	16.8	1,100
N[b]	25	25	25	25	25	25	25	25	25	25
USGS #09306210, Station 103										
Maximum	88	120	4.9	440	1,080	24	32	710	21	1,930
Minimum	42	23	2.5	70	280	0	11	120	9.9	420
Mean	74	86	3.5	228	698	1	20	421	17.2	1,190
N	24	24	24	24	24	24	24	24	24	24
USGS #09306222, Station 104										
Maximum	72	100	8.3	2,000	4,690	389	1,000	570	19	5,280
Minimum	18	18	3.0	76	292	0	11	50	6.1	378
Mean	48	82	4.7	756	1,665	51	157	415	3.8	2,230
N	24	24	24	24	24	24	24	24	24	24

[a] Sum of Constituents.

[b] N = Number of Observations.

Source: Ficke et al. (1974).

TABLE 13. PICEANCE CREEK WATER QUALITY DATA OCTOBER 1972 TO SEPTEMBER 1973 (All values are based on analyses of filtered samples and are expressed in mg/liter except specific conductance which is expressed in μmhos/cm at 25° C.)

Location	N[a]	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Bicarbonates (HCO_3)	Carbonates (CO_3)	Chlorides (Cl)	Sulfates (SO_4)	Silica (SiO_2)	TDS[b]	Specific Conductance
USGS #09306200, Station 102												
Maximum		100	110	3.8	220	750	4	25	500	20	1,330	1,910
Minimum	11	73	75	2.5	120	523	0	12	290	15	851	1,230
Mean		83	84	3.15	176	640	0	15	377	17.7	1,075	1,528
USGS #09306210, Station 103												
Maximum		94	110	3.8	250	802	4	20	570	20	1,460	2,040
Minimum	11	68	67	2.7	140	546	0	13	300	15	892	1,310
Mean		80	84	3.3	197	672	0	16.6	400	18	1,133	1,624
USGS #09306222, Station 104												
Maximum		77	110	6.2	810	1,790	143	120	580	20	2,470	3,531
Minimum	13	34	66	3.0	200	701	0	16	300	14	1,040	1,460
Mean		62	83	4.0	424	1,095	19	57	438	17.2	1,630	2,349

[a] N = Number of Observations.

[b] Sum of Constituents.

Source: Weeks and Welder (1974).

biological productivity of a water body is directly correlated with its hardness. However, hardness, per se, has no biological significance because biological effects are functions of specific ions and combinations of elements (NAS 1973). Many minor dissolved substances contribute to the total hardness and salinity of waters, but as they are usually present only in trace quantities, their total contribution from the standpoint of hardness is rather insignificant.

Effects which may be expected as a result of utilizing waters of varying TDS levels for cropland irrigation and livestock watering were summarized from NAS (1973) (Tables 14 and 15). In terms of these guidelines the surface waters of the Colorado River system are acceptable for livestock watering purposes, but most of the main stem waters have for years exceeded the guideline level for sensitive irrigated crops. Conductivity and TDS values for these waters typically fall into the 750 to 1,500 μmhos/cm and 500 to 1,000 mg/liter ranges, respectively, the level of possible detrimental effects for sensitive crops.

TABLE 14. RECOMMENDED GUIDELINES FOR SALINITY IN IRRIGATION WATERS FOR ARID AND SEMIARID REGIONS

	TDS (mg/liter)	Electrical Conductance (μmhos/cm at 25° C)
Water for which no detrimental effects are usually noticed	500	750
Water that can have detrimental effects on sensitive crops	500-1,000	750-1,500
Water that can have adverse effects on many crops	1,000-2,000	1,500-3,000
Water that can be used on tolerant crops on permeable soils	2,000-5,000	3,000-7,500

Source: Modified From NAS (1973).

Levels of TDS, hardness, and specific constituents which normally represent maximum acceptable limits for particular industrial purposes were summarized from NAS (1973) (Table 16). While ambient surface water quality throughout the Colorado River system is acceptable for a wide range of industrial uses, concentrations of specific constituents which exceed the recommended limits for cooling purposes and certain industrial process uses have been reported (Tables 9, 10, and 11). Piceance Creek waters exceed the

TABLE 15. GUIDELINES FOR THE USE OF SALINE WATERS FOR LIVESTOCK AND POULTRY

TDS (mg/liter)	Comment
Less than 1,000	Relatively low level of salinity. Excellent for all classes of livestock and poultry.
1,000- 2,999	Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to them, or water droppings in poultry.
3,000- 4,999	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to them. Poor waters for poultry, often causing watery feces, increased mortality, and decreased growth, especially in turkeys.
5,000- 6,999	Can be used with reasonable safety for dairy and beef cattle, sheep, swine, and horses. Avoid use for pregnant lactating animals. Not acceptable for poultry.
7,000-10,000	Unfit for poultry and probably for swine. Considerable risk in using for pregnant or lactating cows, horses, sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
Over 10,000	Risks with these highly saline waters are so great that they cannot be recommended for use under any conditions.

Source: Modified from NAS (1973).

TABLE 16. SUMMARY OF SPECIFIC QUALITY CHARACTERISTICS OF SURFACE WATERS THAT HAVE BEEN USED AS SOURCES FOR INDUSTRIAL WATER SUPPLIES (All values are maximums and are expressed in mg/liter.)

Water Use	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na + K)	Bicarbonates (HCO_3)	Sulfates (SO_4)	Chlorides (Cl)	Silica (SiO_2)	TDS	Hardness ($CaCO_3$)
Boiler makeup:									
Industrial 0 to 1,500 psig[a]	...	...	...	600	1,400	19,000	150	35,000	5,000
Utility 700 to 5,000 psig	...	...	...	600	1,400	19,000	150	35,000	5,000
Cooling:									
Freshwater -									
Once through	500	...	...	600	680	600	50	1,000	850
Makeup recycle	500	...	...	600	680	500	150	1,000	850
Brackish water[b] -									
Once through	1,200	...	...	180	2,700	22,000	25	35,000	7,000
Makeup recycle	1,200	...	...	180	2,700	22,000	25	35,000	7,000
Industrial processing:									
Textile	...	...	...	...	...	...	...	150	120
Pulp and paper	...	...	...	...	...	200	50	1,080	475
Chemical	250	100	...	600	850	500	...	2,500	1,000
Petroleum	220	85	230	480	900	1,600	85	3,500	900
Mining-									
Copper sulfide concentrator	1,500[c]	...	...	...	1,634	12	...	2,100	1,530
Copper leach solution	...	12,000	...	...	64,000	...	...	...	...

[a] Pounds per square inch.

[b] Water containing in excess of 1,000 mg/liter TDS.

[c] $CaCO_3$.

Source: Modified from NAS (1973).

recommended guidelines for a number of industrial purposes (Tables 12 and 13). Oil shale developmental activities on the Piceance Creek watershed are likely to result in further degradation in the quality of the stream.

No specific maximum limits for hardness, or salinity (TDS) or specific ions are specified for the protection of aquatic life. The NAS (1973) report, however, recommended that bioassays and field studies be conducted when dissolved materials are altered to determine the limits that aquatic ecosystems can tolerate without endangering their structure and function.

Drinking water standards prior to 1975 recommended against using waters with a TDS limit exceeding 500 mg/liter (USPHS 1962). This recommendation was not adopted by NAS (1973). Also, in its revised drinking water guidelines USEPA (1975b) did not adopt the previous recommendation since many public drinking water supplies with TDS levels exceeding 500 mg/liter are in current use with no ill effects to the consumers. Both NAS (1973) and USEPA (1975b) did, however, recommend limits of 250 mg/liter for both chlorides and sulfates in public drinking water supplies.

It is estimated that the salt concentrating effects of a 1-million-barrel-per-day industry would increase the salinity at Hoover Dam by 10 to 27 mg/liter, depending on the quantities of water required (USDI 1973, vol. I, p. III-76). The impact on the river would not be immediate, but as high quality ground water supplies decrease and the rate of surface water withdrawal increases, the effects would become more pronounced (USDI 1973, vol. I, pp. III-75, 76).

TOXIC SUBSTANCES

Sources

Many activities associated with the development and operation of an oil shale industry which could potentially increase the total salt burden of surface waters could similarly increase the potential for contamination with a variety of toxic substances including trace elements, pesticides and miscellaneous substances.

Raw and retorted shale contain a number of potentially toxic substances in varying concentrations. Ward et al. (1971) reported on concentrations of minor constituents in water after intimate contact with raw and spent shale (Table 17). Stanfield et al. (1951) and Stanfield et al. (1964) reported on the trace element content of spent shale ash from the Green River Formation in Colorado and Utah (Table 18). Cook (1973) reported the concentration of trace elements in pyrolyzed shale (500° C) from the Mahogany zone in the Piceance Creek Basin of Colorado (Table 19). Although wide discrepancies in the data are apparent, these analyses demonstrate that retorted oil shale contains numerous potentially toxic trace elements which may eventually reach surface waters.

TABLE 17. CONCENTRATIONS OF MINOR CONSTITUENTS IN WATER AFTER INTIMATE CONTACT WITH RETORTED SHALE

Ion	Maximum Concentration Observed (mg/liter)	Source	Test
Al	2.5	TOSCO	Column (first leachate)
Ba	4.0	Raw	Blender
Br	<0.1	. . .	. . . .
Cu	<0.1	. . .	. . . .
Cr	<0.1	. . .	. . . .
F	3.4	UOC	Blender
Fe	1.7	TOSCO	Column (first leachate)
I	0.16	. . .	. . . .
Mn	<0.1	. . .	. . . .
Pb	<0.1	TOSCO	Column (first leachate)
Zn	2.5	TOSCO	Column (first leachate)

Source: Ward et al. (1971).

TABLE 18. CONCENTRATIONS OF TRACE ELEMENTS IN SPENT OIL SHALE ASH FROM THE MAHOGANY LEDGE OF THE GREEN RIVER FORMATION IN COLORADO AND UTAH (All concentrations expressed in mg/kg.)

	Colorado Shale[a]	Utah Shale[b]		Colorado Shale[a]	Utah Shale[b]
Arsenic (As)	50	...	Rubidium (Rb)	...	60
Barium (Ba)	300	300	Selenium (Se)	10	...
Boron (B)	30	136	Silver (Ag)	10	...
Chromium (Cr)	70	170	Strontium (Sr)	800	760
Copper (Cu)	80	100	Thallium (Tl)	7,000	...
Gold (Au)	10	100	Titanium (Ti)	600	1,200
Lead (Pb)	900	...	Vanadium (v)	600	78
Lithium (Li)	500	420	Zinc (Zn)	1,000	35
Manganese (Mn)	800	...	Zirconium (Zr)	...	33
Molybdenum (Mo)	10	70			

Sources: [a] Stanfield et al. (1951).
[b] Stanfield et al. (1964).

TABLE 19. CONCENTRATIONS OF TRACE ELEMENTS IN PYROLIZED OIL SHALE FROM THE MAHOGANY LEDGE OF THE GREEN RIVER FORMATION IN THE PICEANCE BASIN IN COLORADO

Element	Concentration (mg/kg)	Element	Concentration (mg/kg)
Antimony (Sb)	0.39	Molybdenum (Mo)	4.9
Arsenic (As)	7.20	Neodymium (Nd)	1.2
Barium (Ba)	32	Nickel (Ni)	11
Beryllium (Be)	35	Niobium (Nb)	3.4
Bismuth (Bi)	0.36	Osmium (Os)	<0.1
Boron (B)	140	Palladium (Pd)	<0.1
Bromine (Br)	0.01	Platinum (Pt)	<0.1
Cadmium (Cd)	0.14	Praseodymium (Pr)	0.25
Cerium (Ce)	1.6	Rhenium (Re)	<0.1
Cesium (Cs)	1.2	Rhodium (Rh)	<0.1
Chlorine (Ci)	72.0	Rubidium (Rb)	29
Chromium (Cr)	49.0	Ruthenium (Ru)	<0.1
Cobalt (Co)	39.0	Samarium (Sm)	0.44
Copper (Cu)	15.0	Scandium (Sc)	2.4
Dysprosium (Dy)	0.40	Selenium (Se)	0.08
Erbium (Er)	0.27	Silver (Ag)	<0.01
Europium (Eu)	0.12	Strontium (Sr)	69
Fluorine (F)	1,700	Tantalum (Ta)	0.04
Gadolinium (Gd)	0.40	Tellurium (Te)	<0.1
Gallium (Ga)	2.2	Terbium (Tb)	0.07
Germanium (Ge)	0.40	Thallium (Tl)	0.14
Gold (Au)	<0.1	Thorium (Th)	0.77
Hafnium (Hf)	<0.1	Tin (Sn)	0.11
Holmium (Ho)	0.07	Titanium (Ti)	570
Iodine (I)	<0.01	Tungsten (W)	0.42
Iridium (Ir)	<0.1	Uranium (U)	0.99
Lanthenum (La)	1.4	Vanadium (V)	29
Lead (Pb)	10	Ytterbium (Yb)	0.25
Lithium (Li)	850	Yttrium (Y)	1.2
Lutetium (Lu)	0.01	Zinc (Zn)	13
Manganese (Mn)	34	Zirconium (Zr)	9.3
Mercury (Hg)	<0.1		

Source: Modified from Cook (1973).

Leaching studies by Culbertson et al. (1970) and Ward et al. (1972) have shown that soluble salts are readily leached from spent shale piles, but the mobilization potential of minor elements is virtually unknown. Furthermore, since few data are available on the trace element content of raw shales and soils, the potential for release of trace elements from these sources and subsequent transport to waterways as a result of landscape disturbances is unknown.

Other possible sources of trace elements and other toxic substances include stack emissions from processing operations, catalysts and chemicals used in oil upgrading and gas processing, contact of high quality water with highly mineralized ground water, municipal and industrial wastes from expanding communities and development of ancillary extractive industries.

Airborne emissions would include fugitive dust from mining, crushing, and conveying operations, as well as sulfur and nitrogen oxides from retorting operations and power generation. Acid rain frequently associated with mining and processing operations in some areas of the country could conceivably alter the pH and buffering capacities of surface waters, and therefore the toxicity of soluble substances.

Various catalysts and chemicals are required for oil upgrading and gas processing operations (Table 20). All materials except monoethanolamine (MEA) are solids; MEA in spent form is a highly water-soluble sludgelike liquid (USDI 1973, vol. I, p. I-88). The nickel and cobalt molybdate catalysts would be reclaimed at plants outside the area, but the other chemicals, approximately 45.4 metric tons (50 tons) of which would be MEA, would be buried within the shale pile. Release of such waste materials would probably be slow. Over a period of decades or centuries weathering and erosion of the piles would probably expose the materials to runoff waters with unknown consequences.

TABLE 20. CATALYSTS AND CHEMICALS REQUIRED FOR A 50,000-BARREL-PER-DAY OPERATION

Type	Tons Per Year
Nickel and cobalt-molybdate catalysts	1,420
Iron catalysts	158
Monoethanolamine (MEA)	50
Iron oxide	30
Char	10

Source: USDI (1973, vol. I, p. I-88).

Probably the greatest potential source of trace element contamination to both high quality ground water and surface water is the highly mineralized subsurface waters such as those in the Piceance Creek Basin.

Several possibilities exist for handling excess water in initial stages of development including release to streams, treatment and release, or storage in impoundments for future use (USDI 1973, vol. I, p. III-61). As the industry matures and as the water table is lowered, increasing amounts of mineralized water will be encountered and require disposal. Subsurface reinjection of these highly mineralized waters into a lower aquifer has been proposed as a means of disposing of excess low quality waters (USDI 1973, vol. I, p. III-62). This proposed method could degrade the quality of water in the upper aquifer by upwelling of mineralized waters. Although the quality of water in local streams would not be initially affected, over a period of time upward movement and subsurface discharge of poor quality ground water would undoubtedly impact streams (USDI 1973, vol. I, p. III-65).

Development of a 1-million-barrel-a-day oil shale industry would result in substantial urban growth in the oil shale area. It is estimated that a total population increase of 66,000 to 115,000 persons would be required to support the industry, representing nearly a twofold increase over the 1970 population of the area (USDI 1973, vol. I, p. III-205).

The influx of people to the oil shale area may attract mobile home industries and light manufacturing industries. Industrial growth will undoubtedly be restricted to operations which do not demand large quantities of water.

Potential toxicants which may be introduced to waters as a result of industrial and urban growth include chlorine, cyanide, detergent builders, phenolic compounds, phthalate esters, polychlorinated biphenyls (PCB's), and toxic forms of nitrogen including ammonia, nitrites and nitrates.

Increased levels of pesticides and their residues in waterways can be expected as pesticide usage increases. The creation of new lawns, parks, and recreational facilities will likely result in greater domestic use of pesticides by homeowners and communities. Expanded industrial growth also characteristically results in increased usage of various pesticides, as does maintenance of utility corridors and roadside right-of-ways.

The types and extent of ancillary industrial growth that may be stimulated by oil shale development cannot be predicted with any certainty. The extensive deposits of nahcolite and dawsonite found in association with oil shale may lead to the recovery of soda ash, aluminum, or compounds thereof. Technology for the recovery of sodium materials from these deposits has been demonstrated on a pilot scale, but commercial extraction has not been attempted. Aluminum and aluminum compounds contained in dawsonite have been recovered from retorted shale on a small scale. Trona and halite occur to some extent in the Green River Basin in Wyoming, and sodium materials, petroleum, natural gas, asphalt, tar sands, and coal are scattered throughout the Green River Formation of the oil shale area. It is not presently known if all of these materials are present in commercially significant quantities.

Ambient Levels

Concentrations of trace elements and other toxic substances vary widely throughout the Colorado River system with time and location. Inspection of trace element data summarized from Kopp and Kroner (1969) (Table 21) reveals few conclusive trends with respect to trace metal concentrations relative to location, but a few observations are noteworthy. Arsenic, beryllium, and cadmium were not detected at all and cobalt and vanadium were each reported at only one site; the **former** in the upper Green River and the latter in the upper Colorado. Barium, boron, copper, iron, manganese, strontium, and zinc were reported at all locations, but only boron exhibited conspicuously increasing concentrations in a downstream progression. Silver and molybdenum were detected at all but the lower Colorado main stem stations. The distribution of lead, nickel and aluminum was sporadic, each being detected only in one or two samples at various locations.

Additional data on the range of concentrations of trace metals in the main stem of the Colorado at Yuma, Arizona during 1958-59 were summarized from A. D. Little (1971) (Table 22). Maximum concentrations of aluminum, barium, chromium, copper, iron, and manganese were in the range of those reported by Kopp and Kroner (1969) at the same location, but the latter reported much higher concentrations of boron and strontium. Conversely, nickel concentrations were reported to be an order of magnitude higher during the 1958-59 study than were reported by Kopp and Kroner (1969). Rubidium and titanium were present at Yuma in concentrations of less than 0.01 mg/liter during 1958-59 (A. D. Little 1971).

Maximum concentrations of boron, fluoride, and iron at selected sites on the Colorado, Green, and White Rivers during 1964-65 and 1968-69 were extracted from USGS (1970, 1974) (Table 23). The boron data for the upper watershed are in line with those reported by Kopp and Kroner (1969) (Table 21), however, the USGS data do not show the increase in concentrations in the lower watershed that was so apparent in the Kopp and Kroner (1969) data.

Iron concentrations reported by USGS (1970, 1974) were typically lower than those reported by Kopp and Kroner (1969) and A. D. Little (1971) for the same general area of watershed. Fluoride concentrations were not reported by Kopp and Kroner (1969) or A. D. Little (1971), but USGS (1970, 1974) data show relatively uniform concentrations ranging from 0.30-1.0 mg/liter throughout the watershed.

Voorheis-Trindle-Nelson of Colorado (VTN) measured concentrations of trace elements in the reach of the White River adjacent to Federal land tracts U-a/U-b in Northeastern Utah (Table 24). Although these data represent a relatively short period of sampling (August 1974 - August 1975), they provide an indication of trace element concentrations in this reach of the White River during the predevelopment era.

Data on ambient levels of such toxic substances as chlorine, detergent builders, phenolic compounds, phthalate esters, and PCB's in the Colorado River system are scarce or nonexistent. A single analysis for

TABLE 21. MAXIMUM CONCENTRATIONS OF TRACE MINERALS REPORTED AT SELECTED SAMPLING LOCATIONS ON THE GREEN RIVER AND COLORADO RIVER DURING 1962-67 (All concentrations are expressed as dissolved and in mg/liter.)

Trace Minerals	Green River at Dutch John, Utah		Colorado River at Loma, Colo.		Colorado River at Page, Ariz.		Colorado River at Boulder City, Nev.		Colorado River at Parker Dam, Ariz.		Colorado River at Yuma, Ariz.	
	Max.	N[a]	Max.	N	Max.	N	Max.	N	Max.	N	Max.	N
Aluminum (Al)	0.043	(1/9)	0.029	(1/22)	0.026	(1/9)	---	(0/10)	---	(0/9)	0.125	(1/10)
Arsenic (As)	---		---		---		---		---		---	
Barium (Ba)	0.196	(9/9)	0.082	(22/22)	0.091	(9/9)	0.232	(10/10)	0.156	(9/9)	0.121	(10/10)
Beryllium (Be)	---		---		---		---		---		---	
Boron (B)	0.215	(9/9)	0.232	(22/22)	0.228	(9/9)	0.620	(10/10)	1.036	(9/9)	1.800	(9/10)
Cadmium (Cd)	---		---		---		---		---		---	
Chromium (Cr)	---		0.019	(5/22)	0.011	(1/9)	0.022	(2/10)	0.036	(1/9)	0.034	(2/10)
Cobalt (Co)	0.011	(1/9)	---		---		---		---		---	
Copper (Cu)	0.016	(5/9)	0.035	(7/22)	0.010	(2/9)	0.023	(1/10)	0.020	(3/9)	0.007	(1/10)
Iron (Fe)	0.109	(6/9)	0.062	(11/22)	0.127	(4/9)	0.137	(4/10)	0.251	(4/9)	0.072	(3/10)
Lead (Pb)	---		---		---		0.064	(2/10)	0.038	(1/9)	---	
Manganese (Mn)	0.015	(4/9)	0.049	(11/22)	0.009	(3/9)	0.026	(4/10)	0.020	(3/9)	0.028	(2/10)
Molybdenum (Mo)	0.142	(2/9)	0.444	(18/22)	0.100	(2/9)	0.165	(3/10)	0.074	(4/9)	---	
Nickel (Ni)	0.007	(1/9)	---		---		---		0.027	(2/9)	0.025	(1/10)
Silver (Ag)	0.0045	(2/9)	0.038	(3/22)	0.0035	(1/9)	0.013	(1/10)	---		---	
Strontium (Sr)	0.437	(9/9)	1.800	(22/22)	1.250	(9/9)	1.220	(10/10)	1.221	(9/9)	3.500	(10/10)
Vanadium (V)	---		0.003	(5/22)	---		---		---		---	
Zinc (Zn)	0.036	(4/9)	0.013	(1/22)	0.077	(4/9)	0.259	(5/10)	0.312	(9/9)	0.080	(2/10)

[a] N = (number of positive occurences / total number of observations).

Source: Kopp and Kroner (1969).

TABLE 22. MINIMUM AND MAXIMUM CONCENTRATIONS OF VARIOUS INORGANIC CONSTITUENTS REPORTED IN THE COLORADO RIVER AT YUMA, ARIZONA DURING 1958-59

Constituent[a]	Range (mg/liter)
Aluminum (Al)	0.012 -0.153
Barium (Ba)	0.128 -0.152
Boron (B)	0.034 -0.052
Chromium (Cr)	0.010 -0.024
Copper (Cu)	0.0085-0.0088
Iron (Fe)	0.111 -0.160
Lead (Pb)	0.008 -0.016
Lithium (Li)	0.035 -0.037
Manganese (Mn)	0.021 -0.037
Molybdenum (Mo)	0.0065-0.0069
Nickel (Ni)	0.0 -0.30
Rubidium (Rb)	0.0 -0.008
Strontium (Sr)	0.715 -0.802
Titanium (Ti)	0.008 -0.010

[a] Reported as dissolved.

Source: As compiled by A. D. Little (1971) from Faber and Bryson (1960), and Durum and Haffty (1961).

TABLE 23. MAXIMUM CONCENTRATIONS OF BORON, FLUORIDE AND IRON AT SELECTED SITES ON THE COLORADO, GREEN AND WHITE RIVERS DURING THE 1964-65 AND 1968-69 WATER YEARS (All concentrations are based on analyses of filtered samples and are expressed in mg/liter.)

Location	Boron (B)	Fluoride (F)	Iron (Fe)	Samples
Colorado River near Glenwood Springs, Colo.				
1964-65	0.07	0.50	0.00[a]	3
1968-69	...	...	...	
Green River near La Barge, Wyo.				
1964-65	0.25	0.60	0.02	25
1968-69	0.36	0.40	...	21
Colorado River near Cisco, Utah				
1964-65	0.14	0.50	0.46	4
1968-69	...	1.0	...	6
White River near Watson, Utah				
1964-65	0.12	0.40	0.41	5
1968-69	...	0.60	...	5
Green River at Green River, Utah				
1964-65	0.21	0.40	0.42	4
1968-69	...	0.70	...	12
Colorado River at Lees Ferry, Ariz.				
1964-65	0.15	0.30	0.02	4
1968-69	0.17	0.40	...	2
Colorado River near Grand Canyon, Ariz.				
1964-65	0.51	0.30	0.11	4
1968-69	0.17	0.40	0.01	2
Colorado River below Hoover Dam, Ariz. and Nev.				
1964-65	0.25	0.40	0.02	12
1968-69	0.21	0.40	0.02	3
Colorado River below Parker Dam, Ariz. and Calif.				
1964-65	...	...	...	
1968-69	0.21	0.40	0.01	2

[a] One sample

Source: USGS (1970,1974).

TABLE 24. MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS REPORTED AT FOUR SITES ON THE WHITE RIVER ADJACENT TO LEASED TRACTS U-a/U-b DURING PERIOD FROM AUGUST 1974 to AUGUST 1975 (All concentrations are based on analyses of filtered samples.)

Trace Element	Concentration (mg/liter)	Trace Element	Concentration (mg/liter)
Aluminum (Al)	6.0	Lead (Pb)	0.007
Arsenic (As)	0.004	Lithium (Li)	<0.11
Barium (Ba)	0.14	Manganese (Mn)	0.082
Beryllium (Be)	<0.01	Mercury (Hg)	<0.0004
Bismuth (Bi)	<0.015	Molybdenum (Mo)	0.006
Boron (B)	0.19	Nickel (Ni)	0.016
Cadmium (Cd)	<0.004	Selenium (Se)	0.004
Chromium (Cr)	<0.02	Silver (Ag)	<0.002
Cobalt (Co)	0.002	Strontium (Sr)	1.3
Copper (Cu)	0.34	Tin (Sn)	<0.012
Fluoride (F)	0.4	Titanium (Ti)	0.6
Gallium (Ga)	<0.006	Vanadium (V)	0.01
Germanium (Ge)	<0.017	Zinc (Zn)	0.18
Iron (Fe)	0.270	Zirconium (Zr)	0.03

Source: VTN 4th and 5th quarterly reports, (1975).

methylene blue active substances (MBAS) on the White River near Watson, Utah yielded concentrations of 0.02 mg/liter [USGS data from USEPA's water quality computerized STOrage and RETrieval system (STORET)]. Water analysis for PCB's on filtered, unfiltered, and suspended samples yielded no positive results, but a single mud analysis revealed a concentration of 2.0 μg/kg on the Colorado River near Cisco, Utah (USGS data from STORET).

Cyanide and phenol data were collected by VTN on the White River stations adjacent to tracts U-a/U-b and on Evacuation Creek which transects the sites (Table 25). Eighty-six analyses of White River water for phenols and fifty analyses for cyanide revealed maximum concentrations of 0.014 mg/liter and 0.01 mg/liter, respectively. Maximum concentrations in Evacuation Creek were 0.024 mg/liter for phenols (30 analyses) and 0.02 mg/liter for cyanide (18 analyses).

Low levels of chlorinated hydrocarbon pesticide residues have been detected in the Colorado River system by a number of investigators. A. D. Little (1970) summarized levels of organochlorine pesticides which have been reported at various locations in the Colorado River system during 1964-68 (Table 26). Sufficient data are not available to discern trends with respect to time or location.

TABLE 25. RANGES AND MEAN CONCENTRATIONS OF PHENOLS AND CYANIDES REPORTED IN THE WHITE RIVER AND EVACUATION CREEK ADJACENT TO TRACTS U-a/U-b DURING THE PERIOD AUGUST 1974 to AUGUST 1975 (All concentrations are expressed in mg/liter.)

	Phenols			Cyanides		
Stations	Maximum	Mean	N[a]	Maximum	Mean	N
White River:						
S-1	0.009	0.0031	23	0.01	0.00	13
S-3	0.006	0.0034	19	0.01	0.00	12
S-4	0.014	0.0041	23	0.01	0.00	13
S-11	0.014	0.0037	21	0.01	0.00	12
Evacuation Creek:						
S-2	0.025	0.0044	19	0.01	0.0015	12
S-6	0.024	0.0038	19	0.02	0.004	11
S-7	0.014	0.0050	15	0.01	0.001	9

[a] N = Number of Observations

Source: VTN (1975) 4th and 5th quarterly reports.

Impact

Since metals and other toxic substances are usually present in waters in trace quantities, they are of little significance in the total contribution to the mineralization problem from an industrial water use standpoint. However, unusually high concentrations of trace elements in intake waters may substantially increase treatment costs.

Ambient water quality data (Tables 21 through 24) indicate trace metals in surface waters of the Colorado River Basin do not constitute a problem from an industrial use standpoint as ambient levels are well below the water quality limits prescribed for particular industrial uses (Table 27).

Toxic substances in surface waters are primarily of concern because of their potential impact on the aquatic biota, agriculture, and man. Since the impacts of toxic materials on freshwater biota, livestock, irrigated crops, and man are discussed in great detail by McKee and Wolf (1963), National Technical Advisory Committee (1968), and NAS (1973), they are only superficially addressed in this report.

TABLE 26. CONCENTRATIONS OF VARIOUS PESTICIDES REPORTED AT SELECTED LOCATIONS IN THE COLORADO RIVER SYSTEM DURING 1964-68 (All concentrations are expressed in μg/liter.)

	Colorado River at Loma, Colo.		Colorado River at Page, Ariz.		Colorado River at Boulder City, Nev.		Colorado River at Parker Dam, Ariz. and Calif.		Colorado River at Yuma, Ariz.	
Pesticide	Concentration	Year	Concentration	Year	Concentration	Year	Concentration	Year	Concentration	Year
Aldrin	---	---	0.085[a]	1964	Present[a]	1964	---	---	0.02[b]	1967
Benzene Hexachloride	0.006[c]	1966	---	---	---	---	---	---	---	---
Dieldrin	0.008[a]	1964	0.006[a]	1964	0.002[a]	1964	Present[a]	1964	Present[a]	1964
	0.002[c]	1966	0.003[c]	1966	---	---	---	---	0.005[a]	1966
DDE	---	---	---	---	---	---	---	---	0.004[a]	1964
	---	---	---	---	---	---	---	---	0.010[d]	1966
DDT	Present[a]	1964	Present[c]	1966	---	---	---	---	0.021[a]	1964
	---	---	0.058[e]	1965	---	---	---	---	0.070[d]	1966
	---	---	---	---	---	---	---	---	0.010[b]	1967
	---	---	---	---	---	---	---	---	0.010[b]	1968
Endrin	---	---	0.012[a]	1964	---	---	Present[a]	1964	Present[a]	1964
	---	---	Present[e]	1965	---	---	---	---	0.015[a]	1966
Heptachlor	---	---	Present[e]	1965	Present[a]	1964	---	---	0.01[b]	1967
Heptachlor Epoxide	---	---	Present[e]	1965	---	---	---	---	0.005[d]	1966
Lindane	---	---	---	---	---	---	---	---	0.005[d]	1966

Source:

[a] **Weaver et al. (1965), as compiled by A. D. Little (1970).**

[b] **Manigold and Schulze (1969), as compiled by A. D. Little (1970).**

[c] **Green et al. (1966), as compiled by A. D. Little (1970).**

[d] **Brown and Nishioka (1967), as compiled by A. D. Little (1970).**

[e] **Briedenbach et al. (1967), as compiled by A. D. Little (1970).**

TABLE 27. MAXIMUM CONCENTRATIONS OF SPECIFIC CONSTITUENTS IN WATERS THAT HAVE BEEN USED AS SOURCES FOR INDUSTRIAL WATER SUPPLIES (All concentrations are expressed in mg/liter.)

Water Use	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Fluoride (F)
Boiler makeup:					
Industrial 0 to 1,500 psig[a]	3	80	10	---	---
Utility 700 to 5,000 psig	3	80	10	---	---
Cooling:					
Freshwater -					
Once through	3	14	2.5	---	---
Makeup recycle	3	80	10	---	---
Brackish water[b] -					
Once through	---	1.0	0.02	---	---
Makeup recycle	---	1.0	0.02	---	---
Processing:					
Industrial -					
Textile	---	0.3	1.0	0.5	---
Pulp and paper	---	2.6	---	---	---
Chemical	---	10	2	---	---
Petroleum	---	15	---	---	1.2
Mining - copper leach solution	12,000	12,000	---	---	---
Oil recovery injection -					
Seawater	---	0.2	---	---	---
Formation water	---	13	---	---	---

[a] Pounds per square inch gauge.

[b] Water containing in excess of 1,000 mg/liter TDS.

Source: Modified from NAS (1973).

Many naturally occurring dissolved substances in water, although vital to life functions in trace amounts, when present in high concentrations, they can prove harmful or fatal to plants and animals, including man. The toxic properties of trace metals such as arsenic, copper, and zinc, all essential to human nutrition, are well known, and various compounds of these metals have been used for years in the manufacture of pesticides.

The toxicity of metals in water varies considerably with the chemical and physical characteristics of the water. For example, the pH of water influences the solubility and, therefore, the toxicity of many metals including aluminum, copper, and zinc. The presence of certain metals in water can enhance the toxicity of other metals by synergistic reactions. For example, the toxicity of zinc, cadmium and mercury is increased by the synergistic action of copper. On the other hand, the toxic effects of many metals, including zinc, copper, lead, cadmium, chromium, and nickel, are much less pronounced in highly mineralized (hard) waters than in soft waters owing to the antagonistic action of calcium, carbonates, and other common hard water constituents.

Cadmium, lead, chromium, and mercury are examples of nonessential, nonbeneficial elements in the diet which are highly toxic to aquatic life, humans, and livestock in low concentrations. Boron, cobalt, and molybdenum are known to be essential to higher plants in trace quantities, but may be deleterious to crops if highly concentrated in irrigation waters.

Water quality criteria recommendations for maximum concentrations of a number of trace elements in waters to be used for cropland irrigation, and for the protection of aquatic life, livestock, and human health were summarized by NAS (1973) (Tables 28 and 29). Ambient surface water data for waters within the Colorado River system (Tables 21 through 24) reveal that the maximum concentrations of boron, molybdenum, and nickel exceeded the acceptable limits for continuous irrigation at several locations. Maximum concentrations of iron and lead at some stations in the lower Colorado exceeded the recommended limits for drinking water. Lead concentrations in one sample in the lower Colorado near Boulder City, Nevada also exceeded the maximum acceptable limit for aquatic life.

These comparisons of water quality criteria with ambient water quality data clearly illustrate that concentrations of certain trace minerals in Colorado River Basin surface waters at times exceed the maximum acceptable limits for specified water uses. The utility of these waters can only be further impaired by activities which disturb large areas of the landscape, create large volumes of waste material for disposal, alter surface water and ground water regimens and lead to increased usage of chemicals in the area unless such developmental activities are carefully planned and closely regulated.

Although concentrations of trace minerals in the surface of the Colorado River Basin are not exceptionally high when compared with river basins in heavily industrialized areas of the country, the extent to which the surface water characteristics will be altered by industrialization and urbanization of the area is unknown. For example, arsenic and cadmium, both highly toxic

TABLE 28. WATER QUALITY CRITERIA FOR MAXIMUM RECOMMENDED CONCENTRATIONS OF TRACE ELEMENTS IN CROPLAND IRRIGATION WATERS (The concentration is expressed in mg/liter.)

Parameter	Criteria	Parameter	Criteria
Aluminum (Al)	5.0	Iron (Fe)	5.0
Arsenic (As)	0.1	Lead (Pb)	5.0
Beryllium (Be)	0.1	Lithium (Li)	2.5
Boron (B)	0.75	Manganese (Mn)	0.2
Cadmium (Cd)	0.01	Molybdenum (Mo)	0.01
Chromium (Cr)	0.1	Nickel (Ni)	0.2
Cobalt (Co)	0.05	Selenium (Se)	0.02
Copper (Cu)	0.2	Vanadium (V)	0.1
Fluoride (F)	1.0	Zinc (Zn)	2.0

Source: NAS (1973).

metals, are common constituents of rocks and could be released to the aquatic ecosystem through weathering of the exposed bedrock, or as leachates from spent shale. Numerous additional heavy metals could be released to waterways in quantities sufficient to seriously impair the utility of these waterways for specific beneficial uses.

In the Colorado River Basin, pesticides may constitute the greatest potential hazard of all toxic substances of nonpoint source origin. Pesticides include a myriad of natural and synthetic chemicals used to control or destroy plant and animal species under a variety of situations. Depending on the intended use or target organisms, pesticides are frequently categorized as insecticides, herbicides, fungicides, rodenticides, nematicides, etc.

The major threat of contamination of waterways arises from insecticides and herbicides, because they are the most widely used categories of pesticides and many are resistant to degradation, persisting in the environment in forms which are toxic to aquatic and terrestrial life, including humans. The entry of pesticides into waterways in large doses, as frequently occurs with spills or accidental discharges, may have an immediate and dramatic impact resulting in annihilation of the biota and poisoning of public water supplies. More frequently, however, pesticide pollution of waterways has a more subtle effect as residue levels slowly build up over time.

TABLE 29. WATER QUALITY CRITERIA FOR MAXIMUM RECOMMENDED CONCENTRATIONS OF TRACE ELEMENTS IN WATERS TO BE USED FOR DRINKING WATER, LIVESTOCK AND THE SUPPORT OF AQUATIC LIFE (All concentrations are expressed in mg/liter.)

Parameter	Drinking Water	Livestock	Aquatic Life
Aluminum (Al)	NL[a]	5.0	NL
Arsenic (As)	0.1	0.2	NL
Barium (Ba)	1.0	NL	NL
Boron (B)	NL	5.0	NL
Cadmium (Cd)	0.01	0.05	0.0004-0.03
Chromium (Cr)	0.05	1.0	0.05
Cobalt (Co)	NL	1.0	NL
Copper (Cu)	1.0	0.5	AF[b]
Fluoride (F)	1.4-2.4	2.0	NL
Iron (Fe)	0.3	NL	NL
Lead (Pb)	0.05	0.1	0.03
Manganese (Mn)	0.05	NL	NL
Mercury (Hg)	0.002	0.01	0.00005
Selenium (Se)	0.01	0.05	NL
Vanadium (V)	NL	0.1	NL
Zinc (Zn)	5.0	25.0	AF

[a] NL = No Limits.

[b] AF means a safety factor is applied to LD_{50} bioassay data derived with a sensitive species sought to be protected.

Source: NAS (1973).

TABLE 30. RECOMMENDED MAXIMUM CONCENTRATIONS OF COMMON INSECTICIDES IN WHOLE (UNFILTERED) WATER FOR THE PROTECTION OF AQUATIC LIFE

Insecticide	Recommended Maximum Concentration (μg/liter)[a]
Organochlorine:	
Aldrin	0.01
DDT	0.002
TDE	0.006
Dieldrin	0.005
Chlordane	0.04
Endosulfan	0.003
Endrin	0.002
Heptachlor	0.01
Lindane	0.02
Methoxychlor	0.005
Toxaphene	0.01
Organophosphate:	
Azinphosmethyl	0.001
Ciodrin	0.1
Coumaphos	0.001
Diazinon	0.009
Dichlorvos	0.001
Dioxathion	0.09
Disulfonton	0.05
Dursban	0.001
Ethion	0.02
EPN	0.06
Fenthion	0.006
Malathion	0.008
Mevinphos	0.002
Naled	0.004
Oxydemeton methyl	0.4
Parathion	0.0004
Phosphamidon	0.03
TEPP	0.4
Trichlorophon	0.0002
Carbamate:	
Carbaryl	0.02
Zoctran	0.1

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[a] Concentrations were determined by multiplying the acute toxicity values for the more sensitive species by an application factor of 0.01.

Source: NAS (1973).

TABLE 31. RECOMMENDED MAXIMUM CONCENTRATIONS OF SELECTED PESTICIDES IN WATERS USED FOR HUMAN INTAKE AND LIVESTOCK

Compounds	Recommended Limit (mg/liter)[a]
Chlorinated hydrocarbons:	
Aldrin	0.001
Chlordane	0.003
DDT	0.05
Dieldrin	0.001
Endrin	0.0005
Heptachlor	0.0001
Heptachlor Epoxide	0.0001
Lindane	0.005
Methoxychlor	1.0
Toxaphene	0.005
Carbamate pesticides (all):	0.1
Organophosphate pesticides (all):	0.1
Chlorophyenoxy herbicides:	
2,4-D	0.02
Silvex	0.03
2,4,5-T	0.002

[a] Concentrations were determined by multiplying acute toxicity values for the more sensitive species by an application factor of 0.01.

Source: NAS (1973).

TABLE 32. RECOMMENDED MAXIMUM CONCENTRATIONS OF HERBICIDES, FUNGICIDES, AND DEFOLIANTS IN WHOLE (UNFILTERED) WATER FOR THE PROTECTION OF AQUATIC LIFE

Compound	Recommended Maximum Concentration (μg/liter)[a]
Herbicides, fungicides, defoliants:	
Aminotriazole	300.0
Dalapon	110.0
Dicamba	260
Dichlobenil	37.0
Dichlone	0.2
Diquat	0.5
Diuron	1.0
2,4-D (BEE)	4.0
Fenac (sodium salt)	45.0
Silvex (BEE)	2.5
Silvex (PGBE)	2.0
Simazine	10.0
Botanicals:	
Allethrin	0.002
Pyrothrum	0.01
Rotenone	10.0

[a] Concentrations were determined by multiplying the acute toxicity values for the more sensitive species by an application factor of 0.01.

Source: NAS (1973).

Most pesticides undergo rapid degradation in the environment and, while highly toxic for a short while, soon are degraded metabolically or otherwise to relatively innocuous materials. On the other hand, some pesticides, particularly the organochlorine insecticides, are extremely resistant to degradation **and** are subject to biological accumulation directly from the water and through the food web. This results in insecticide concentrations in higher trophic-level organisms several thousand times higher than ambient water levels.

Comparison of ambient water quality data for the Colorado River System (Table 26) with water quality criteria recommendations (Tables 30 and 31) reveals that concentrations of aldrin, DDT, dieldrin, and endrin approached or exceeded the recommended maximum levels for the protection of aquatic life, humans, and livestock at various locations. In recent years fish and bird mortalities attributable to organochlorine pesticides have occurred in and downstream from irrigation ditches in the Lower Colorado Basin.

Water quality criteria recommendations for other categories of pesticides (Table 32) and other toxic substances (Table 33) were established by NAS (1973) for various water uses including protection of aquatic life and humans. Since few ambient data on levels of these substances in the Colorado River system are available, it is not known whether or not they constitute a potential hazard.

TABLE 33. VARIOUS TOXIC SUBSTANCES IN WATER AND RECOMMENDED MAXIMUM CONCENTRATIONS FOR THE PROTECTION OF MAN AND AQUATIC LIFE

	Water Use	
Substance	Aquatic Life	Public Water Supply
Chlorine	0.003 mg/liter	NL[a]
Cyanide	0.005 mg/liter/AF[b]	0.2 mg/liter
Detergent, Detergent Builders linear alkylate sulfonate (LAS)	0.02 mg/liter/AF	0.5 mg/liter
Phenolic compounds	0.1 mg/liter/AF	1.0 μg/liter
Phthalate esters	0.3 μg/liter	NL
Polychlorinated Biphenyls (PCB)	0.002 μg/liter	NL

[a] NL = No Limits

[b] AF means a safety factor is applied to LD_{50} bioassay data derived with a sensitive species sought to be protected.

Source: NAS (1973).

Certain toxic substances (Table 33) generally occur in water at hazardous levels only in heavily industrialized metropolitan areas. Consequently, it is unlikely that they pose a serious hazard in the Colorado River Basin at the present time. Accelerated industrial and urban expansion, however, could significantly increase ambient levels of these substances in the aquatic ecosystem.

NUTRIENTS

Sources

The term "nutrient" can legitimately be applied to any element, vitamin, hormone or other substance which is utilized metabolically for growth or maintenance by living organisms. From the standpoint of water quality, the nutrients of major concern are nitrogen and phosphorous owing to their contributions to the eutrophication problems. It is these macronutrients which are addressed in this section.

Both nitrogen and phosphorous enter surface waters by natural and man-induced processes. Nitrogen enters waters naturally through fixation from the atmosphere and through geologic and biogenic processes. Leaching of phosphorous from calcium-phosphate rocks and soils along with the importation of allochthonous organic materials are among the most important natural sources of phosphorous in waters.

Nitrogen and phosphorus loading to waterways occurs as a result of many human activities including agriculture, industrialization, and urbanization. Goldberg (1970) summarized the estimated nutrient contributions of both nitrogen and phosphorus from various common sources (Table 34). It is seen that rural runoff is the single largest contributor of both elements, with domestic wastes the second largest contributor in terms of total poundage.

Potential sources of nitrogen and phosphorus loading to the surface waters as a result of the development of an oil shale industry include municipal wastes, ground water discharge, stack emissions, runoff from raw and spent shales and commercial fertilizers.

The primary effect of urban growth on water quality would result from increased nutrient loading via domestic sewage. Most municipal treatment plants in the Colorado River Basin provide secondary treatment plus disinfection, which is the minimum degree of treatment required by the basin states in populated areas.

An influx of people to the oil shale area will place an added burden on existing sewage treatment plants requiring expansion of existing plants or construction of new facilities if the state's water quality standards are to be met. Increasing the capacity of municipal treatment plants should partially alleviate the problems of additional nutrient releases to surface waters as a result of population growth, but additional loading over the present level is to be expected. Municipal wastes receiving secondary

TABLE 34. ESTIMATES OF NUTRIENT CONTRIBUTIONS FROM VARIOUS SOURCES

Source	Nitrogen: Pounds per year	Nitrogen: Usual concentration in discharge	Phosphorus: Pounds per year	Phosphorus: Usual concentration in discharge
	(millions)	(mg/liter)	(millions)	(mg/liter)
Domestic Waste	1,100-1,600	18-20	200-500	3.5-9.0
Industrial Waste	>1,000	0-10,000	*a*	*a*
Rural runoff:				
Agricultural Land	1,500-15,000	1-70	120-1,200	0.05-1.1
Nonagricultural Land	400-1,900	0.1-0.5	150-750	0.04-0.2
Farm animal waste	>1,000	*a*	*a*	*a*
Urban runoff	110-1,100	1-10	11-170	0.1-1.5
Rainfall[b]	30-590	0.1-2.0	3-9	0.01-0.03

[a] Insufficient data available to make estimate.

[b] Considers rainfall contributed directly to water surface.

Source: Modified from Goldberg (1970).

treatment are very high in plant-available nutrients, consequently the increased volume of treated wastes will result in increased nutrient loading to waterways.

Ground waters in the oil shale area are rich in nitrogen with concentrations of nitrates as high as 55 mg/liter reported from a spring in the Piceance Basin (Coffin, et al. 1968). Data available on phosphorus concentrations in ground water indicate levels are not unacceptably high. Release of ground water to surface waters, regardless of the mechanism, represents a potential source of nitrogen loading, but probably does not represent a significant source of phosphorus.

Stack emissions from industrial operations are a potential source of nitrogen entry to waterways via atmospheric rainout. Nitrogen oxides will be emitted from retorting operations and power generation, but the quantity of nitrogen which will reach waterways via this route is unknown.

Leachates from spent shale piles are another possible mechanism by which both nitrogen and phosphorus could reach surface waters. The study by Ward et al. (1971) of the pollution potential of spent oil shale residues revealed nitrate concentrations of 186 mg/liter in leachates from TOSCO shale and phosphate concentrations of 35 mg/liter. Few data are readily available on concentrations of phosphorus and nitrogen in oil shale and soils in this area. Goldberg (1970) points out that organic-rich shales can be a source of nitrogen in water, with some Miocene shales contributing up to 8,600 mg nitrogen/kg shale. Analysis of pyrolized shale by Stanfield et al. (1951) and Stanfield et al. (1964) did not include nitrogen data, but concentrations of phosphorus by weight were reported as 4,000 mg/kg and 1,500 mg/kg, respectively. The potential for nitrogen and phosphorus release to surface water from spent shale is unknown, but owing to the high concentrations of these elements in the shales a potential certainly exists.

Ambient Levels

Nitrate nitrogen was the only nutrient parameter routinely measured and reported by USGS for the Colorado, Green, and White Rivers during the 1964-65 and 1968-69 water years (USGS 1970, 1974). Maximum nitrate values reported at selected stations reveal abnormally high concentrations in the Colorado River at Cisco, Utah and the Green River at Green River, Utah (Table 35). Such extremely high values are of questionable validity as nitrate values in excess of 5.0 mg/liter in surface waters are rare.

Additional nutrient data on the reach of the White River adjacent to tracts U-a/U-b in Utah during the period August 1974 through August 1975 were reported by VTN (1975) (Table 36). Ignoring the obviously erroneous values reported for orthophosphorus and orthophosphate at Station S-3, the data indicate nutrient levels in this reach of the White River were not excessively high during this period.

TABLE 35. AMBIENT LEVELS OF NITRATE NITROGEN (NO_3 - N) IN THE COLORADO, GREEN AND WHITE RIVERS AT SELECTED LOCATIONS DURING WATER YEARS 1965 AND 1969 (All concentrations are based on analyses of filtered samples and are expressed in mg/liter.)

Colorado River Glenwood Springs, Colo.			Colorado River Cisco, Utah			White River Watson, Utah			Green River Green River, Utah			Colorado River Lees Ferry, Arizona		
N[a]	Max	Min	N	Max	Min	N	Max	Min	N	Max	Min	N	Max	Min
1965														
3	0.8	0.1	31	29.0	0.9	17	2.2	0.2	4	4.7	1.3	4	4.0	2.4
1969														
17	1.1	0.0	47	13.0	0.7	5	4.3	0.1	12	12.0	0.8	14	5.5	3.1

[a] N = Number of observations.

Source: USGS (1970, 1974).

TABLE 36. AMBIENT NUTRIENT DATA FOR THE WHITE RIVER NEAR TRACTS U-a/U-b, AUGUST 1974 - AUGUST 1975 (All concentrations are based on analyses of filtered samples and expressed in mg/liter.)

	Station S-1 Hells Hole Canyon			Station S-3 Ignatio Station			Station S-4 Southam Canyon			Station S-11 Asphalt Wash		
	[a]N	Max	Mean	N	Max	Mean	N	Max	Mean	N	Max	Mean
Ammonia	24	.29	.05	24	.19	.05	24	.12	.04	22	.15	.05
Nitrite	24	.01	.00016	23	.01	.00	24	.04	.01	22	.03	.00
Nitrate	23	.50	.127	22	.39	.12	22	1.1	.13	21	.52	.14
Kjeldahl	24	4.9	1.06	26	3.3	.72	24	7.6	1.11	22	2.5	.60
$NO_2 + NO_3$	24	.51	.12	27	.37	.12	23	1.1	.13	22	.54	.14
Orthophosphate	24	.12	.053	27	210[b]	7.82[b]	24	.18	.06	22	.12	.05
Phosphorous	24	.47	.143	23	1.1	.19	24	1.9	.37	22	.61	.14
Orthophosphorous	24	.04	.02	27	68[b]	2.53[b]	24	.06	.02	22	.04	.018

[a] N = Number of observations.

[b] Obviously erroneous value.

Source: VTN 4th and 5th Quarterly Reports (1975).

Impact

The significance of nitrogen and phosphorus in aquatic ecosystems is well documented in the literature. A great deal of published information discussing the role of these nutrients in the eutrophication process is referenced by Mackenthun (1965), Likens (1972), and many others. For the purpose of this discussion, let it suffice to say that nitrogen and phosphorus are the two major nutrients most frequently singled out for control or removal at waste treatment plants in an attempt to slow the eutrophication process. Any nutrient can limit productivity if unavailable in quantities sufficient to meet the minimum requirements of the biota relative to the availability of other nutrients. However, many of the micronutrients need only be present in minute quantities to satisfy basic biological requirements and their control or removal is prohibitively costly, if indeed possible. Furthermore, the removal of nitrogen and phosphorus at sewage treatment plants can frequently be effected with existing technology and at feasible costs, thereby limiting productivity and alleviating the eutrophication problem in a given water body.

Nutrients in various forms as well as the excessive productivity they induce in aquatic systems can interfere with beneficial water uses. NAS (1973) did not establish numerical water quality nutrient criteria for purposes of limiting the productivity of aquatic life. It is necessary to know the productivity responses of various water types to ambient nutrient levels if realistic numerical limits are to be prescribed for ambient nutrient concentrations or loading rates. Such relationships are presently being developed and tested at EMSL-LV utilizing data obtained from lakes sampled in the National Eutrophication Survey and may provide a basis for the development of numerical criteria.

NAS (1973) established criteria for particular nutrient forms for beneficial water uses. Included were criteria for waters used for industrial purposes, public water supplies, and livestock watering. In addition, criteria were established for the protection of aquatic life from toxic ammonia (Table 37).

Examination of water use criteria data (Table 37) suggests Colorado River waters are acceptable for most beneficial uses, providing the abnormally high nitrate values are erroneous. Additional nutrient loading in the Colorado River system resulting from an oil shale industry and associated urban development would undoubtedly adversely impact localized reaches of streams, but the cumulative impact on the Colorado River system cannot be predicted with certainty. The rate of loading will depend in part upon the distribution and density of the human population, as well as the degree of treatment which the wastes receive.

TABLE 37. NUTRIENT WATER QUALITY CRITERIA FOR DESIGNATED BENEFICIAL WATER USES (All units are in mg/liter.)

Nutrient Form	Water Use			
	Public Water Supply	Livestock	Industrial Purposes	Aquatic Life
Ammonia	0.5	NL[a]	40.0	0.02/AF[b]
Nitrates	10.0	100.0[c]	8.0[c]	NL
Nitrites	1.0	10.0	NL	NL
Phosphates	NL	NL	4.0[d]	NL

[a] NL = No limit.

[b] AF means a safety factor is applied to LD_{50} bioassay data derived with a sensitive species sought to be protected.

[c] Includes nitrates and nitrites.

[d] Only the most stringent industrial use criteria are listed.

Source: NAS (1973).

HYDROGRAPHIC MODIFICATION

General

Hydrographic modification refers to procedures that change the movement, flow or circulation of any navigable waters or ground waters (USEPA 1975a). An in-depth examination of all potential disturbances which could alter the water balance of the oil shale area or the Colorado River Basin is beyond the scope of this report. Consequently, in the following discussion, selected types of anticipated disturbances and their potential impacts are examined in an attempt to provide insight into problems associated with hydrographic modification and requirements for assessing the problems.

Anticipated disturbances can be categorized by the manner in which they alter water systems as follows: (1) creation of new impoundments, (2) drainage of existing impoundments, (3) diversion of natural drainage, (4) flow depletions, and (5) disturbances to streambeds.

Creation of New Impoundments

Withdrawal of surface waters for operational purposes will require the construction of new reservoirs to assure an adequate supply of water during all seasons. Since the Uinta Basin apparently does not contain large ground water reserves, oil shale development in that area is contingent upon the availability of surface waters. The White River is being considered as a potential location for a reservoir to trap flood waters as a means of providing a dependable supply to support operations on the Utah tracts. Plans for the construction of the dam are not firm as appropriation rights are somewhat clouded (See Section 2 of this report for further discussion of available sources of surface waters).

Storage ponds may be required to store water imported to the tract site and possibly to store excess water pumped from aquifers during mine dewatering operations. The number and size of ponds which may be required for these purposes are indefinite at present.

Additional impoundments may be required for disposal of liquid and slurry wastes and for the containment of mud slides and spent shale or leachates in the event of failure or leaching of disposal piles.

Drainage of Existing Impoundments

It is not anticipated that any major reservoirs will be modified by developmental or operational activities, but small ponds in the area may be drained or altered. Since ponds in the area are not abundant, such occurrences would be uncommon.

Diversion of Natural Drainage

Natural drainage patterns will be disrupted by the network of roads, powerlines and pipelines required to provide access and services to the area and to transport oil and wastewater from the processing sites (USDI 1973, vol. I, p. III-21). Streams and washes will be disrupted by construction of roads and utility corridors, but such disturbances are generally temporary and localized. Diversion channels will be constructed along roadways to handle storm runoff and to decrease the potential for washout.

Disposal of overburden and spent shale in box canyons will result in eventual obliteration of the canyons and complete alteration of their drainage patterns. Streamflow and runoff will have to be routed over, under, or around the spent shale piles to provide adequate drainage, thereby minimizing the potential for leaching of pollutants and failure of the disposal piles.

Flow Depletions

Consumptive uses of surface and ground water for industrial operations and associated urban development would result in substantial reductions in both the quantity and quality of available surface waters. Projected water requirements and available sources of water for various levels of industrial development are discussed in detail in Section 2 of this report.

Streambed Disturbance

Streambed disturbance resulting from installation of culverts, and/or temporary diversions, will be common. Since such disturbances usually are confined to short reaches of streams, physical stabilization and biological recolonization of such areas is usually rapid.

Impact

Historically, mining operations have been equated with landscape destruction and water quality degradation. Typically, mining operations involve the movement and relocation of large volumes of extracted material resulting in drastic changes in the topography and drainage characteristics of exploited areas. The oil shale industry is similar to most other extractive mining and processing industries in that large expanses of the landscape will be disturbed by the development and operation of a commercial industry resulting in permanent alteration of the water storage and drainage system.

The evolution of the oil shale industry, however, differs from that of most mining industries in that initial development will occur primarily on Federal lands under rigid government controls and regulations instituted to minimize the environmental impact of such development. Although the development of the industry will occur in strict adherence to environmental guidelines, unavoidable deleterious consequences will inevitably result. Many of the disturbances will be localized and temporary, and the damage repairable. These disturbances although locally and temporarily significant, do not permanently alter the regional hydrological regimes. Conversely, those disturbances which potentially alter the water budget of entire river systems could seal the fate of the industry in the early developmental stages.

Activities such as road building, pipeline installation, shale disposal, mine dewatering, etc., could permanently alter the hydraulics of streams in the area. Ground water withdrawals will probably have the greatest impact as continuous pumping over a period of years could dry up a number of springs in the Piceance Basin and eliminate much of the seepage to surface waters. Mine dewatering at the rate of 0.85 m^3/s (30 ft^3/s) for a **30-year period in** the C-a tract would lower the entire water table within an **8-mile radius** of the site (USDI 1973, vol. I, p. III-70). Up to 37 springs within this area would experience adverse effects ranging from reduction of flow to complete cessation of flow (USDI 1973, vol. I, p. III-70). Reduction in total flows from springs will ultimately reduce the amount of water reaching Yellow Creek. If excess ground water of suitable quality is available to replenish flows, changes in stream hydraulics will be minimal. In the event high quality ground water is not available to replenish surface flow, however, ground water withdrawal could have a substantial impact on the hydrological regimes of the area.

The number of canyons to be used for disposal of spent shale and overburden depends upon the mining and disposal methods used (USDI 1973, vol. I, pp. III-11-30). Surface mining will require overburden disposal sites which are not required for underground methods. Backfilling of surface or underground mines with spent shale would substantially reduce the total area and number of canyons required for shale disposal. For example, if tract C-b is mined with underground techniques, and backfilling is not practical, three canyons would be required for disposal and each would be filled to a depth of 75 m for several kilometers (USDI 1973, vol. I, p. III-14). If backfilling is practiced, 60% of the spent shale could be placed in the mined out area and a single canyon would be required for disposal of the remaining material (USDI 1973, vol. I, p. III-15). Backfilling also greatly reduces the potential for subsidence. Subsidence, if it occurs, could result in significant modification of stream courses. Until mining and disposal methods to be used at each site are specified, the extent to which water courses will be altered cannot be determined. It is obvious that changes will result regardless of the methods employed. However, the extent of alteration can be minimized where underground mining methods and backfilling are practiced.

Construction of dams to impound flowing waters destroys endemic terrestrial or lotic communities in the inundated area, but in so doing creates habitats for potential colonization by lentic aquatic species. Although the impact of impoundment construction obliterates established biotic communities, the long-term effects are not without certain benefits.

Reservoirs trap sediments and stabilize downstream flows, thus creating more favorable habitats for some aquatic organisms. Dams which effectively reduce sediment loads and the frequency and severity of flooding generally result in colonization by greater numbers of aquatic plants and animals, both in terms of diversity and total abundance, than formally occupied the stream reach. Terrestrial and semi-aquatic communities may also become more stably established along stream banks once flooding is curtailed.

MICROORGANISMS

Possibilities exist for the microbial contamination of surface waters as a consequence of rapid population increases resulting in overloaded sewage treatment facilities and the subsequent discharge of improperly treated sewage. Bacteria, viruses, protozoa, and fungi are all potential waterborne transmitters or causative agents of diseases. The extent to which public health might be affected by expanded population cannot be projected at this time (USDI 1973, vol. I, p. III-100). Proper precautionary sanitation measures and construction or expansion of adequate sewage treatment facilities would minimize risks of microbial contamination of waterways, and subsequent potential public health hazards.

RADIOACTIVITY

Sources

Assessment of naturally occurring radionuclides found in oil shale has not been extensive. Natural radioactivity is inherent to oil shale as a result of its genesis from the decay of ubiquitous uranium-238.

Lee et al. (1976) computed the atmospheric emissions expected to be released by a 100,000-barrel-per-day mining, retorting, and upgrading operation (Table 38). Concentrations of uranium (U), thorium (Th), and potassium (K) in the spent shale are reported by Lee et al. (1976) as 0.99 mg/liter, 0.77 mg/liter and 2.72% respectively.

The retorting process removes the organic portion of the oil shale, thus concentrating the mineral matter in the spent shale. In order to determine relative amounts of U, Th and K in raw or unprocessed shale, the spent shale concentrations are multiplied by the percent of mineral matter in the raw shale. Considering that mineral matter in the 35-gallon-per-ton oil shale is 82.6% and assuming that all U, Th, and K remain in the spent shale during retorting, the uranium-238, thorium-232 and potassium-40 concentrations in raw Colorado oil shale would be 0.82 mg/liter, 0.64 mg/liter and 2.7% respectively.

The assumption made by Lee et al. (1976) that all the uranium-238, thorium-232 and potassium-40 contained in the shale remain through the retort process is supported by sketchy data collected by the USEPA's Las Vegas Office of Radiation Programs (Michael O'Connell, personal communication, December 8, 1976). The data indicate only small differences between the raw oil shale and the retorted or spent shale with respect to uranium and radium concentrations.

Ambient Levels

Analysis of both ground water and surface water data in the Colorado River and its tributaries indicate high levels of radioactivity may exist (USGS data from STORET). Gross alpha readings for the Green River near Green River, Utah indicate a maximum of 40 picocuries/liter (pCi/liter), and a mean of 12 pCi/liter. Analysis in 1972 of well water on Federal tract C-b indicates the maximum dissolved beta activity expressed as cesium-137 to be 250 pCi/liter (USGS data from STORET).

The United States Geological Survey expresses beta activity in equivalent amounts of either cesium-137 or strontium-yttrium-90; therefore, the beta activity reported is not cesium-137 or strontium-yttrium-90. Tritium levels on the main stem of the Colorado River have been reported as high as 2,280 hydrogen-3 units or approximately 7,300 pCi/liter near Cisco, Utah (USGS data taken from STORET). U.S. Geological Survey data for surface waters of the Colorado River Basin show suspended beta expressed as cesium-137 to be 400 pCi/liter and dissolved beta expressed as cesium-137 to be 14 pCi/liter (STORET data).

TABLE 38. RADIONUCLIDE EMISSIONS TO THE AIR FROM A 100,000-BARREL-PER-DAY OIL SHALE MINING, RETORTING, AND UPGRADING OPERATION

Radionuclide	Dust (μCi/day)	Gases (μCi/day)	Particulates (μCi/day)
Uranium-238	0.64		4.9
Thorium-234	0.64		4.9
Protactinium-234	0.64		4.9
Uranium-234	0.64		4.9
Protactinium-234	0.64		4.9
Thorium-230	0.64		4.9
Radium-226	0.64		4.9
Radon-222	--	32,800	--
Polonium-214	0.64		4.9
Lead-214	0.64		4.9
Bismuth-214	0.64		4.9
Polonium-214	0.64		4.9
Lead-210	0.64		4.9
Bismuth-210	0.64		4.9
Polonium-210	0.64		4.9
Thorium-232	0.16		1.3
Radium-228	0.16		1.3
Actinium-228	0.16		1.3
Thorium-228	0.16		1.3
Radium-224	0.16		1.3
Radon-220	--	8,300	--
Polonium-216	0.16		1.3
Lead-212	0.16		1.3
Bismuth-212	0.16		1.3
Polonium-212	0.10		0.9
Thallium-208	0.06		0.4
Potassium-40	40		310.0
Total	50.4	41,100	390.3

Source: Modified from Lee, et al. (1976).

High levels of suspended gross beta relative to dissolved gross beta can be attributed to an increase in suspended sediments. Since gross alpha and gross beta are typically reported in radioactivity nuclide per unit volume (pCi/liter) rather than radioactivity per unit weight (pCi/g) the occurrence of substantial amounts of suspended sediments in a sample may lead to gross radioactivity values much higher than would be expected were there little or no sediment.

Radiochemical data collected by the USEPA's Environmental Radiation Branch of the Environmental Monitoring and Support Laboratory-Las Vegas, (USEPA 1976a) indicates ambient levels of radionuclides in ground waters and surface waters of the Colorado River System are well below the USEPA drinking water standards (USEPA 1976b).

Impact

The USEPA Drinking Water Regulations for radionuclides (USEPA 1976b) (Table 39) specify that strontium-90 levels shall not exceed 8 pCi/liter, tritium 20,000 pCi/liter, gross alpha 15 pCi/liter and that radium-226 and radium-228 combined not exceed 5 pCi/liter.

TABLE 39. NATIONAL DRINKING WATER REGULATIONS FOR RADIOACTIVITY

Parameter	Regulation
Gross Alpha[a]	15 pCi/liter
Gross Beta[b]	50 pCi/liter
Radium combined 226, 228	05 pCi/liter
Strontium 90	08 pCi/liter
Tritium (H_3)	20,000 pCi/liter

[a] When the gross alpha particle activity exceeds 5 pCi/liter further analysis is required to define the alpha contributors.

[b] Implied limit, not expressly given as a regulation.

Source: USEPA (1976b).

An environmental impact study is currently underway in the Uinta Basin, one portion of which addresses radioactive contaminants derived from oil shale. The information available from this study indicates that for a prototype industry, there is no clear or distinct threat of radioactive contamination. However, no reliable data have been gathered on the impacts resulting from mining or land reclamation concerning increased mobility of uranium and radium by water saturation of the disturbed areas. It is clear that a need exists for further research into this area.

OIL AND GREASE

The possibilities for oil losses exist wherever oil is produced, processed, or transported. It is estimated that a mature 1-million-barrel-per-day industry will require about 280 km (150 miles) of new pipeline to transport shale oil to major existing pipelines (USDI 1973, vol. I, p. III-183). Predicted loss through spillage due to pipeline transport ranges from 1-100 barrels/yr (USDI 1973, vol. I, p. III-183). However, the potential for much larger volume spills exists.

In the event a large-volume spill reaches a waterway and the oil cannot be contained or removed, very severe damage to the aquatic biota and waterfowl would result. Smaller volume spills, such as those resulting from smaller pipeline leaks, could cause local damage to the biota, and if undetected for a long period of time, the damage could be substantial.

Oil and grease in public water supplies can also cause objectionable taste, odor and appearance problems, and can be hazardous to human health (NAS 1973). To avoid such problems, NAS (1973) recommends that public water supply sources be essentially free from oil and grease.

Aquatic life and wildlife should be protected where the following NAS (1973) criteria are observed:

(1) no visible oil on surface of waters,

(2) emulsified oils do not exceed 0.05 of the 96-hr LC_{50} value,

(3) concentrations of hexane-extractable substances (exclusive of elemental sulfur) in air-dried sediments do not increase above 1,000 mg/kg on a dry weight basis.

TEMPERATURE

Causes of Temperature Alteration

Temperature differences between the upper and lower reaches of the Colorado River system are pronounced during all seasons due primarily to climatic, geographic, and topographic factors. Natural temperature regimes of the river system are disrupted by large reservoirs such as Flaming Gorge

Reservoir on the Green River and Lakes Powell and Mead on the Colorado River. The effect of the reservoirs is to lower summer temperatures and in some cases increase winter temperatures for considerable distances downstream from the discharge.

Thermal springs, waste discharges, and irrigation return flows may increase the temperatures of receiving waters locally, but heat added from these sources is usually dissipated quickly.

As the oil shale industry matures, stream temperatures may be altered somewhat by municipal and industrial waste discharges, consumptive uses of surface waters, lowering of the ground water table, landscape modifications, and construction of new reservoirs. A major potential for temperature increases is the discharge of heated water (used in cooling processes) from power generating plants.

Impact

Considering the vastness of the Colorado River System and the inherent wide natural variability in temperatures, thermal effects resulting from oil shale development are expected to be of little significance in terms of the natural temperature regime of the river system (USDI 1975, vol. I, p. III-98).

Temperature is not a critical factor for water used for industrial, agriculture, or public water supply purposes; but aquatic biota could be adversely affected by localized thermal effects as aquatic invertebrates and fish are very sensitive to temperature changes.

Many fish species can tolerate fairly wide ranges in temperature but reproduction and growth can only occur within fairly narrow ranges. Cold-water species, such as trout, for example, are found in waters whose winter temperatures may drop below freezing and whose summer maximum may exceed 22° C, while growth for such species occurs between 3.3° and 14.4°C (USDI 1973, vol. I, p. III-181). If water temperatures in spawning grounds are elevated beyond 12.8° C during the spawning seasons, successful reproduction may not occur, even though adults may continue to flourish (USDI 1973, vol. I, p. III-181).

Extremes, variations, and particularly sudden changes in temperature impact all components of the aquatic ecosystem. Temperature extremes and changes not only affect the biota directly, but also influence their susceptibility to disease and toxic compounds; likewise it affects the solubility of oxygen and other gases, decomposition rates of organic materials, and the community structure and stability of aquatic ecosystems. Because temperature criteria for various aquatic species are so poorly defined and variable, no attempt is made here to present recommended limits. For a discussion of temperature requirements for various aquatic species, see NAS (1973), Section III "Freshwater Aquatic Life and Wildlife, Heat and Temperature", pages 151-171.

SEDIMENTS

Sources

Erosion, transport, and deposition of particulate matter are natural geologic sedimentation processes which have been in continuous operation for millions of years. Much of the oil shale area is highly susceptible to both wind- and water-induced natural sedimentation processes owing to the semiarid climatic condition and the rugged topography characterizing much of the area. The rather scant vegetation affords little protection against soil loss in an area which receives much of its precipitation as snowfall and torrential thunderstorms and is frequently exposed to high velocity, turbulent winds.

Development of an oil shale industry and associated activities will exacerbate sedimentation problems by disturbing large expanses of the landscape, thereby increasing the susceptibility of the area to erosion. Some land forms are known to be less stable than others and, consequently, more subject to erosion, but no attempt has been made to characterize the land forms in the area as to their relative stability.

It is also known that three basic processes are most significant in affecting erosion: (1) the scouring and transport of sediment by intermittent and ephemeral streams, (2) slope erosion (sheet erosion, channel erosion, and gullying of slopes), (3) downslope mass movement of consolidated materials (Everett et al. 1974). However, the potential contribution of each process to the total sediment load of perennial streams in the area has not been quantified. These problems will have to be answered, at least in part, before sedimentation sources can be identified and the relative contribution of each to the stream sediment loads determined.

It is estimated that a 1-million-barrel-per-day industry would affect an aggregate area of approximately 32,376 hectares (80,000 acres) over a 30-year period, of which 20,235 hectares (50,000 acres) would be required for actual production (disposal etc.), while the remainder would be required for utility corridors, roads, and urban expansion (USDI 1973, vol. I, p. III-12). Accelerated sedimentation would necessarily result from such industrial disturbances to the landscape as removal and deposition of overburden for open pit mining; the construction of roads and pipelines and the disposal of spent shales in high canyons, etc. The questions that emerge, however, are: to what degree will erosion and sedimentation be increased; what materials will be most susceptible to movement; and what will be the impact on waterways? At the present time, these questions cannot be answered given the current state of knowledge of the sedimentation potential and processes in the area.

Ambient Levels

Suspended sediment levels have been measured by USGS at several sites throughout the Colorado River Basin since the early 1930's. In general, depth integrated samples were collected daily, but during periods of high flow or variable discharge, measurements were made as frequently as two or three times daily. During periods of stable flow, samples for a number of days were composited to obtain average daily loads (USGS 1970). Monthly ranges of suspended sediment concentrations at selected sites on the Colorado, Green and White Rivers are summarized for water years 1965 and 1969 (Table 40). These data, summarized from USGS (1970, 1974), provide an indication of the great seasonal variability in concentrations of suspended sediment in these waters.

The total suspended sediment load in transport is a function of concentration and discharge. Generally maximum sediment transport occurs during periods of maximum discharge, but this is not always the case. The manner in which precipitation and runoff occurs greatly influences the suspended sediment concentration in flowing water and therefore the total quantities of sediments in suspension. For example, much of the late spring and early summer, flow is derived from snowmelt in the upper watershed. If snowmelt is gradual, these waters may be relatively low in suspended sediment concentration since little erosion and subsequent sediment transport has occurred. On the other hand, highly intense summer thunderstorm activity may induce severe erosion resulting in very high suspended sediment loading to receiving water.

Impact

The composition and concentration of suspended sediments in surface waters are important because of their effects on light penetration, temperature, solubility products and aquatic life. Sediments in industrial waters also erode power turbines and pumping equipment.

Absorption of light by natural waters is strongly affected by the presence of suspended materials. Since the growth of aquatic plants is regulated by the intensity of sunlight, suspended sediments may be one of the most important factors influencing the productivity of a water body.

Because suspended sediment inhibits sunlight penetration, water temperature may be affected by the concentration of sediment suspended in surface waters. Highly turbid lentic waters warm more rapidly than clearer waters, inducing pronounced thermal stratification early in the season which may persist for several months. Vertical mixing of lentic waters is inhibited by such warming of the surface layers reducing oxygen transfer to the underlying water. Consequently, the increasing turbidity could alter the temperature patterns and oxygen regimes of lakes and reservoirs thus creating unfavorable habitats for the endemic biota.

Sediment deposition in flood plains damages valuable crops and croplands. The scouring action of streambed sediments damages and kills aquatic organisms, both plant and animal, and destroys their habitats.

The transport of sorbed pollutants by sediments is a major mechanism by which pesticides and nutrients enter and are dispersed in waterways. Chlorinated hydrocarbons, nutrient phosphates, and numerous other pollutants have a high affinity for clay particles which are easily transported to streams via wind and surface runoff.

TABLE 40. MAXIMUM DAILY SUSPENDED SEDIMENT CONCENTRATIONS[a] AT SELECTED LOCATIONS (All values are expressed in mg/liter.)

Month	Colorado River near Cisco, Utah		Green River at Green River, Utah		Colorado River at Lees Ferry, Ariz.		Colorado River near Grand Canyon, Ariz.	
	1964-65	1968-69	1964-65	1968-69	1964-65	1968-69	1964-65	1968-69
October	120	3,020	810	1,270	49		3,800	12,200
November	270	790	450	174	66		1,300	912
December	1,700	197	930	442	90		6,000	300
January	800	2,850	410	555	670		13,000	7,620
February	660	3,050	3,200	665	820		4,400	2,520
March	740	1,030	5,200	4,320	2,000		12,000	2,920
April	8,900	5,880	7,000	5,910	2,100		13,000	3,740
May	6,600	2,140	4,600	3,320	940		5,200	900
June	3,200	13,000	6,000	5,000	680		2,500	846
July	14,000	3,490	14,000	1,410	17		21,000	8,900
August	14,800	6,580	12,000	23,800	20		15,000	3,920
September	4,900	5,350	7,900	12,900	-		8,600	11,400

[a] Values published by USGS are daily means based on one or more measurements per day; values given in this table are the maximum daily means per month.

Source: USGS (1970, 1974).

Sediments produce direct detrimental effects to fish and their food organisms. The European Inland Fisheries Advisory Board (EIFAB) lists the following ways in which sediments may prove harmful to the fisheries of a lake or river (EIFAB 1965):

(1) By acting directly on the fish swimming in water in which solids are suspended, and either killing them or reducing their growth rate, resistance to disease, etc.

(2) By preventing the successful development of fish eggs and larvae.

(3) By modifying natural movements and migrations of fish.

(4) By reducing the abundance of food available to the fish.

(5) By affecting the efficiency of methods for catching fish.

With respect to chemically inert suspended solids and to waters that are otherwise satisfactory for the maintenance of freshwater fisheries, EIFAB (1965) reported:

(1) There is no evidence that concentrations of suspended solids less than 25 mg/liter have any harmful effects on fisheries.

(2) It should usually be possible to maintain good or moderate fisheries in waters which normally contain 25 to 80 mg/liter suspended solids. Other factors being equal, however, the yield of fish from such waters might be somewhat lower than those yielded by category (1) waters.

(3) Waters normally containing from 80 to 400 mg/liter suspended solids are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at the lower concentrations within this range.

(4) At the best, only poor fisheries are likely to be found in waters which normally contain more than 400 mg/liter suspended solids.

Based on the findings of the EIFAB (1965), NAS (1973) established the following criteria for the protection of aquatic communities:

	Suspended Sediments
High level of protection	25 mg/liter
Moderate level of protection	80 mg/liter
Low level of protection	400 mg/liter
Very low level of protection	over 400 mg/liter

NAS (1973) also established maximum concentrations of suspended sediments in waters used for a variety of industrial purposes. In general, industrial uses of freshwaters are not impaired unless suspended solids concentrations exceed 1,000 mg/liter. Concentrations as high as 15,000 mg/liter are the maximum acceptable levels for boiler and cooling makeup water.

Maximum suspended sediment concentrations in the Green and Colorado Rivers exceeded the least restrictive water quality criteria limits for aquatic life nearly every month of the year.

DISSOLVED OXYGEN

Sources of Oxygen and Causes of Depletion

Dissolved oxygen in surface waters is derived from two principal sources: (1) from the atmosphere directly by diffusion at the surface and through surface water agitation, and (2) from photosynthetic activity of chlorophyll-bearing plants (Welch 1952). Ground water and surface runoff may at times contribute substantially to the oxygen content of streams, particularly if the subsurface flow is over broken rocks shortly before reaching the surface and if overland runoff is rapid and vigorous (Reid 1961). However, since ground water is frequently low in dissolved oxygen content and since vigorous overland runoff is usually sporadic and coincident with intense rainfall, the former source may be more of a liability to the dissolved oxygen budget than an attribute, and the latter an unreliable source at best.

In clear quiet waters the photosynthetic activity of phytoplankton and rooted vascular plants may be the primary source of oxygen during daylight hours (Welch 1952). During the night, an oxygen deficit may develop in such waters as diffusion from the atmosphere may be inadequate to replenish the oxygen consumed.

Lentic waters exposed to wind action and turbulent flowing waters derive oxygen directly from the atmosphere, and, if the water is clear, through photosynthesis as well. In the near-shore wave swept zones of lakes and in tortuous headwater stream reaches attached (lithophytic) algae may be the most significant photosynthetic producers of oxygen. Oxygen deficits rarely occur in clear, well-agitated waters. In fact the net production of oxygen in upstream reaches frequently contributes to the oxygen content in the more turbid, calmer downstream waters (Reid 1961).

While a number of forces are functioning to provide oxygen, opposing factors tend to reduce the available oxygen supply, the following factors are of major significance in reducing the oxygen supply in surface waters:

(1) Respiration of living organisms - Respiration of plants and animals is a continuing process which utilizes dissolved oxygen. The effects of respiration on oxygen supply are most conspicuous during the night when photosynthetic activity has ceased, thereby causing substantial diurnal fluctuations in dissolved oxygen levels.

(2) Oxidation of organic matter - Bacterial action on oxidizable solids such as those in sewage creates a biological oxygen demand which may exceed the rate of oxygen replenishment resulting in a deficit in the oxygen budget some distance downstream from the source. As the oxygen deficit, which is cumulative, increases, uptake also increases at a rate proportional to the oxygen deficit (Hynes 1963). Consequently, as the amount of organic materials decrease, the rate of oxygen production exceeds that of consumption resulting in an increase in the oxygen level.

(3) Temperature - The solubility of oxygen varies inversely with temperature. Consequently, raising the water temperature decreases the solubility of oxygen resulting in a loss of oxygen from the water.

(4) Atmospheric pressure - Since the solubility of oxygen in water varies directly with atmospheric pressure, a reduction in pressure results in a decrease in dissolved oxygen concentrations.

(5) Inorganic reactions - Certain inorganic reactions in lakes and streams, such as the oxidation of ferrous iron, sulfite and sulfides, may contribute to the immediate loss of oxygen.

(6) Inflow of tributaries - The inflow of tributaries of low oxygen content tends to decrease the content of receiving waters. Tributaries receiving the bulk of their flow from springs and ground water seepage are of particular significance in this respect.

Undoubtedly, organic loading to waterways and subsequent biological activity associated with the digestion of oxidizable materials are the most common causes of oxygen reduction in most surface waters. The oxygen demand exerted by a given volume of water is approximately proportional to the amount of oxidizable materials in the water. Consequently, the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) tests are frequently used to estimate the requirements of a given water for oxygen or to quantitatively evaluate the pollution load (Hem 1970). The BOD test, however, is of limited value in measuring the oxygen demand of surface waters in which levels of oxygen-demanding organic substances are low. The extrapolation of test results to actual stream oxygen demands is highly questionable since the laboratory environment does not produce stream conditions (APHA 1971). Both the BOD and COD tests have their widest application in measuring waste loadings to treatment plants and to evaluate the efficiency of such plants.

In some instances a rough correlaation between BOD, COD, and total organic carbon (TOC) has been established (APHA 1971). When such an empirical relationship can be established the TOC determinations provide a speedy and convenient way of estimating the other parameters that express the degree of organic contamination (APHA 1971).

Ambient Levels

Dissolved oxygen, chemical oxygen demand, and the total organic carbon data compiled by USGS over recent years are summarized for selected Colorado, Green and White River stations (Table 41). Inspection of the dissolved oxygen data indicates these waters are generally well aerated as mean dissolved oxygen values equaled or exceeded 8.0 mg/liter at all sites. Since stress conditions for the biota are induced by short periods of oxygen deficiency, minimum values may be of greater significance than means with respect to fish populations and aquatic invertebrates. The minimum dissolved oxygen values recorded in the upper Colorado did not fall below 7.0 mg/liter, indicating an ample oxygen supply is available year round. On at least one occasion, however, total oxygen depletion was reported in the Green River at Green River, Utah. Minimum oxygen values of 5.3 mg/liter were recorded on the White River near Watson on at least one occasion, and mean values were substantially below those reported in the upper Colorado. Minimum and maximum and mean dissolved oxygen values in the lower Colorado Site at Lees Ferry were typically lower than those in the upper reaches at Cisco, Utah and Glenwood Springs, Colorado (Table 41).

Chemical oxygen demand data were rather scarce with replicate analyses being reported at only 2 of the 8 sites selected as representative of the river system; one on the main stem of the lower Colorado below Parker Dam. The highest range of values was reported for the White River station with a maximum of 81.0 mg/liter recorded and on at least one occasion none was detectable.

Total organic carbon data were available for six of the eight stations, but were based upon fewer analyses per station than the chemical oxygen demand data. Mean TOC values ranged from a low of 4.2 mg/liter in the lower Colorado to highs of 9.3 and 9.2 in the upper Colorado and Green Rivers, respectively.

USGS/VTN data taken from WATSTORE[a] on the reach of the White River adjacent to tracts U-a/U-b suggest all three parameters are highly variable within an 18-mile stream reach (Table 42). Dissolved oxygen values ranged from 2.4 mg/liter at station S-4 to a high value of 15.0 mg/liter at station S-3. COD values ranged from a low of 0.0 mg/liter at stations S-1 and S-3, to a maximum of 200 mg/liter at station S-4. TOC values followed a similar pattern with values ranging from a low of 2.1 mg/liter at station S-1, to a high of 48 mg/liter reported at station S-4.

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[a] A USGS computerized WATer data STOR(E)age (WATSTORE) system.

TABLE 41. MAXIMUM, MINIMUM, AND MEAN DISSOLVED OXYGEN, CHEMICAL OXYGEN DEMAND AND TOTAL ORGANIC CARBON LEVELS REPORTED AT SELECTED LOCATIONS ON THE GREEN, WHITE AND COLORADO RIVERS DURING THE PERIOD 1968-76 (All concentrations are expressed in mg/liter.)

	Colorado River at Glenwood Springs, Colo.				Colorado River at Cisco, Utah				White River near Watson, Utah			
	N[a]	max	min	mean	N	max	min	mean	N	max	min	mean
Dissolved Oxygen	55	12.5	7.0	9.6	42	14.2	7.1	10.0	64	15.0	5.3	8.8
Chemical Oxygen Demand (C.O.D.)	-	-	-	-	-	-	-	-	29	81.0	0	15.2
Total Organic Carbon (T.O.C.)	-	-	-	-	5	16.0	3.7	9.3	6	14.0	3.1	7.0

	Green River near Green River, Utah				Colorado River at Lees Ferry, Arizona			
	N	max	min	mean	N	max	min	mean
Dissolved Oxygen	44	13.6	0	9.4	44	9.8	6.0	8.0
Chemical Oxygen Demand (C.O.D.)	1	9.7	9.7	9.7	-	-	-	-
Total Organic Carbon (T.O.C.)	9	20.0	3.8	9.1	6	14.0	1.0	5.8

[a] N = Number of observations.

Source: USGS data acquired via STORET, (1976).

TABLE 42. MAXIMUM, MINIMUM, AND MEAN DISSOLVED OXYGEN, CHEMICAL OXYGEN DEMAND, AND TOTAL ORGANIC CARBON VALUES REPORTED IN THE WHITE RIVER, UTAH DURING THE PERIOD 1974-76 (All concentrations are expressed in mg/liter.)

	Hells Hole Canyon S-1				Ignatio S-3			
	N[a]	max	min	mean	N	max	min	mean
Dissolved Oxygen	14	11.1	6.0	8.4	21	15.0	6.4	9.08
Chemical Oxygen Demand	26	140	0	22.7	29	81	0	14.8
Total Organic Carbon	5	39	2.1	10.8	6	14	3.1	7.0

	Southam Canyon S-4				Asphalt Wash S-11			
	N	max	min	mean	N	max	min	mean
Dissolved Oxygen	15	11.7	2.4	8.1	16	11.9	3.8	8.5
Chemical Oxygen Demand	28	200	2	30.4	29	40.0	1.0	13.9
Total Organic Carbon	5	48.0	3.1	14.7	6	8.8	2.8	6.05

[a] N = Number of observations.

Source: USGS Computerized data storage bank, WATSTORE, (1976).

Impact

The consequences of exposure of fish and aquatic invertebrates to low oxygen levels have been the subject of numerous investigations. In-depth review of oxygen requirements of aquatic life have been presented by Duodoroff and Shumway (1967), Doudoroff and Warren (1962), Ellis (1937) and Fry (1960). One of the most comprehensive reviews was prepared by Douderoff and Shumway (1970) for the Food and Agricultural Organization (FAO) of the United Nations. The FAO recommendation, although slightly modified, served as a basis for NAS (1973) in developing dissolved oxygen water quality criteria for the protection of fish and aquatic life.

The NAS approach to establishing dissolved oxygen water quality criteria for the protection of fish and aquatic life differs substantially from previous efforts by other investigators. Whereas previous water quality criteria recommended separate limits for the protection of warm water and rough fish (ORSANCO 1955), or warm water and cold water biota (NTAC 1968), the NAS document made no such distinction, but provides for various levels of protection to be afforded all aquatic life based upon socioeconomic decisions.

It is the contention of NAS (1973) that there is no evidence to indicate the more sensitive warm water species have lower dissolved oxygen requirements than the more sensitive cold water fishes. It is acknowledged, however, that many warm water species are exceedingly tolerant of oxygen deficiency (NAS 1973). The NAS document also makes an assumption that the dissolved oxygen requirements of other aquatic communities are compatible with fish even though certain important invertebrates may be more sensitive to low dissolved oxygen than fish (Doudoroff and Shumway 1970).

No single arbitrary recommendation can be set for dissolved oxygen concentrations that will be favorable for all kinds of fish in all kinds of water or even a single kind of fish in a single water (NAS 1973).

In light of these considerations, the NAS document offers a choice of four levels of protection to be afforded a given water body and fisheries depending on the degree of protection desired; namely maximum, high, moderate, or low. The selection document outlines the requirements of the species to be protected, natural seasonal minimal oxygen concentrations in the water body and corresponding temperatures of oxygen-saturated freshwater. A minimum value of 4.0 mg/liter is recommended, except for waters which have a natural dissolved oxygen level of less than 4.0 mg/liter, in which case no further depression is desirable (NAS 1973). The 4.0 mg/liter minimum is selected because evidence indicates subacute or chronic damage to several fish may occur below this concentration (NAS 1973).

Since waters of the Colorado River system differ dramatically in the types of fisheries they support, seasonal temperature maxima, and major uses, it would be beyond the scope of this report to review ambient dissolved oxygen levels in terms of the NAS water quality criteria described above. Anaerobic conditions have been reported in the Green River (Table 41) and minimum values below the 4.0 mg/liter recommended minimum have been reported at two of the White River stations near the leased tracts. Therefore, it is obvious that stress conditions for a balanced fishery exist at times in the lower reaches of both streams. Further depression of oxygen levels could be induced by oil shale developmental activities and related industrial and urban development thereby further jeopardizing the aquatic biota in these areas.

Any introduction of oxidizable materials, whether organic or inorganic, creates an additional oxygen demand through increased biological or chemical activity, or both. The primary potential sources of such materials would undoubtedly be municipal wastewater discharges, but industrial discharges and diffuse sources including ground water seepage also constitute a potential threat. Increased oxygen consumption through respiration and decomposition of aquatic biota may follow a general enrichment of localized stream reaches resulting from increased nutrient impact as discussed in the previous subsection.

ACIDITY, ALKALINITY, pH, AND CARBON DIOXIDE

Relationships and Causes of Variations

Acidity and alkalinity are related terms. Acidity is produced by substances that yield hydrogen ions; alkalinity is produced by substances that produce hydroxyl ions (NTAC 1968). Acidity in natural waters is caused by carbon dioxide, mineral acids, weakly dissociated acids and the salts of strong acids and weak bases. Alkalinity is caused by strong bases and the salts of strong alkalies and weak acids (NTAC 1968).

Determinations of pH provide an indication of acidity and alkalinity, but are not a direct measurement of either. Total acidity by definition is the amount of standard alkali required to bring the pH of a single sample to 8.3; total alkalinity is the amount of standard acid required to bring a sample to pH 4.5 (NTAC 1968). Since the titration points for both measurements are pH dependent, a relation between acidity, alkalinity and pH is apparent. Water with a pH below 4.5 has no measurable alkalinity and water with a pH greater than 8.3 has no measurable acidity (NTAC 1968). Water with a pH between these values may have both acidity and alkalinity.

The pH of most natural waters usually falls in the 6.0-9.0 range. Under some circumstances pH values greatly outside this range may occur in natural waters. For example, Hutchinson (1957) mentions pH values as low as 1.7 reported in a volcanic lake and values of 12.0 in an effluentless alkaline lake.

The pH of water receiving industrial wastes and mine drainage may be drastically altered by the addition of acids or alkalies. Such additions, particularly in poorly buffered systems, not only result in acidic or alkaline conditions, but may increase the toxicity of various components in the water (NAS 1973). In well-buffered systems the addition of small quantities of acids has little effect on the pH of the system.

The susceptibility of a given water to changes in pH values as a result of additions of acids and alkalies is a function of the buffering capacity of that water. The buffering capacity of freshwater in turn is dependent upon the bicarbonate content of the water (Ruttner 1953). Most running waters are bicarbonate waters in the limnological sense showing complicated relationships between pH, CO_3^{2-}, HCO_3^-, H^+, CO_2, H_2CO_3, Ca^{2+} and Mg^{2+} (Hynes 1970). These relationships are discussed in detail by Ruttner (1953), Hutchinson (1957) and Reid (1961). For the purposes of this discussion it is sufficient to stress a few points summarized by Hynes (1970):

1) Rainwater reaching watercourses or runoff from bogs, dense forest litter and similar substrata tends to have a low pH due to the hydrogen ions produced by the **dissociation of carbonic acid and the loss of** cations by base exchange with organic matter.

2) Water which has percolated through the soil is also rich in carbon dioxide and similarly tends to be rich in hydrogen ions ($H_2O + CO_2 \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$).

3) Calcium carbonate which is a common constituent of many rocks is almost insoluble in water, but it dissolves rapidly as bicarbonate in carbonic acid, and it neutralizes the soil where it occurs ($CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2 \rightleftharpoons Ca^{2+} + 2HCO_3^-$).

4) Calcium bicarbonate in solution is a good buffer system and thus resists change in pH, but it remains in solution only in the presence of a certain amount of free carbon dioxide, the so called equilibrium CO_2. Therefore, any process which removes carbon dioxide, as does photosynthesis, tends to precipitate calcium from solution, especially where the bicarbonate is abundant.

Alkalinity in water is contributed by bicarbonates, carbonates and hydroxides. In most natural systems alkalinity is practically all produced by dissolved bicarbonates and carbonate ions.

Any ion that enters into a chemical reaction with strong acid can contribute to titrated alkalinity provided the reaction takes place significantly above the pH of the specified end point (Hynes 1970). However, for the most part alkalinity is produced by anionic or molecular species of weak acids (primarily carbonic acid found when carbon dioxide is dissolved) which are not fully **dissociated above a pH of 4.5 (Hynes 1970).**

Frequently alkalinity is expressed in terms of an equivalent quantity of calcium carbonate, and such terms as methyl-orange alkalinity, and phenolphthalein alkalinity are encountered. Results obtained from these determinations can be used to stoichiometrically calculate relationships of these principal forms of alkalinity and ascribe the entire alkalinity to bicarbonates, carbonates and hydroxides. This classification system ignores alkalinity attributable to weak acids such as silics, phosphorous and boric acids which do contribute to titratable alkalinity. For a discussion of alkalinity relationships the reader is referred to Hynes (1970) and Standard Methods (APHA 1971).

It is common practice with the USGS to report alkalinity in terms of concentrations of bicarbonates since in most natural waters these anions produce practically all the alkalinity (Hem 1970). For additional details on units of reporting and relationships between pH, alkalinity, and various carbon dioxide species, the reader is referred to Hem (1970).

Ambient Levels

Since data on levels of bicarbonates and carbonates occurring at selected sites throughout the Colorado River system were presented and discussed under the salinity subsection of this report, they will not be repeated here. This portion presents pH data and, where available, data on the concentrations of free carbon dioxide at selected locations in the Colorado River system (Tables 43, 44). It should be borne in mind that carbon dioxide dissolved in such naturally circulating waters appears in chemical analyses principally as bicarbonate and carbonate ions (Hem 1970). It is also worth mentioning that the Colorado River System is a well-buffered bicarbonate system, which means that the addition of carbon dioxide to the system through respiration and decay will not usually lower the pH substantially as minerals which act as proton receptors are present in great abundance in the water.

Impact

The NAS Water Quality Criteria document prescribed numeric pH limits for most beneficial water uses (Table 45). Acidity and alkalinity limits were specified only for water designated as industrial supplies (Table 46).

The most restrictive pH limits (6.5-8.3) are for waters used primarily for recreation and aesthetics or for those waters where a high level of protection for aquatic life is sought with pH limits of 6.5-8.5. The least restrictive limits are for specific industrial uses such as primary metals industries and make-up water for freshwater cooling systems with pH limits of 3.0-9.0 and 3.5-9.0 respectively.

Since ambient levels within the Colorado River system generally do not fall below pH 6.5 or above pH 8.5, most water within the basin can be considered acceptable for most beneficial uses with respect to these parameters.

Although Colorado River waters are fairly alkaline, they do not exceed the recommended limits prescribed (Table 46). Colorado River system waters contain suficient CO_2 to maintain equilibrium in the bicarbonate system. It is doubtful that oil shale developmental activities will substantially alter the buffering capacity of the system unless considerable quantities of acids are discharged to waterways. Substantial changes in pH or alkalinity (bicarbonate) levels would serve as an immediate alarm that the buffering system has been disturbed and the equilibrium upset, thereby signaling the need for intensive investigation to determine the cause of the disturbance.

TABLE 43. RANGES AND MEAN pH[a] VALUES REPORTED IN COLORADO RIVER BASIN SURFACE WATER AT SELECTED LOCATIONS DURING 1964-65 AND 1968-69

	Colorado R. near Glenwood Springs, Colo.				Colo. R. near Cisco, Ut.				Green R. near LaBarge, Wyo.			
	N[b]	max	min	mean	N	max	min	mean	N	max	min	mean
1964-65	24	8.2	7.2	7.6	31	8.1	7.5	7.8	25	7.9	6.5	7.2
1968-69	17	8.2	6.7	7.4	47	8.1	6.6	7.6	21	8.4	7.1	7.8

	White R. near Watson, Ut.				Green R. at Green R., Ut.				Colorado River at Lees Ferry, Ariz.			
	N	max	min	mean	N	max	min	mean	N	max	min	mean
1964-65	34	8.3	7.5	7.8	32	8.5	7.5	7.8	18	7.9	7.5	7.6
1968-69	56	8.5	7.2	7.9	49	8.2	7.3	7.8	17	8.5	7.4	7.9

	Colorado R. near Grand Canyon, Ariz.				Colo. R. below Hoover Dam, Nev. & Ariz.				Colo. R. below Parker Dam, Ariz.			
	N	max	min	mean	N	max	min	mean	N	max	min	mean
1965-65	19	7.9	7.6	7.7	12	8.0	7.5	7.8	14	8.3	7.4	7.8
1968-69	12	8.0	7.5	7.8	12	8.0	7.6	7.8	12	7.9	7.4	7.6

[a] Mean pH values are time weighted.
[b] N = Number of observations.
Source: USGS (1970, 1974).

TABLE 44. RANGES AND MEAN pH AND CO_2 VALUES IN THE WHITE RIVER ADJACENT TO LEASED TRACTS U-a/U-b AUGUST 1974 to AUGUST 1975 (All CO_2 values are expressed in mg/liter.)

	Hells Hole Canyon S-1				Ignatio S-3				Southam Canyon S-4				Asphalt Wash S-11			
	N[a]	max	min	mean	N	max	min	mean	N	max	min	mean	N	max	min	mean
pH:																
Aug 74 - Apr 75	10	8.5	7.8	8.2	14	8.6	7.9	8.2	11	8.5	7.8	8.2	8	8.6	7.6	8.3
May 75 - Aug 75	6	8.6	8.0	8.3	6	8.4	7.4	8.1	6	8.8	7.2	8.1	4	8.3	7.6	7.9
CO_2:																
Aug 74 - May 75	10	6.7	1.1	3.0	4	4.6	1.5	2.4	11	5.6	1.2	3.3	8	8.2	1.0	2.8
May 75 - Aug 75	6	2.3	0.6	1.5	6	10.0	1.2	3.3	6	17.0	0.4	4.3	4	8.2	1.9	4.1

[a] N = Number of observations.

Source: VTN 4th and 5th Quarterly Reports, (1975).

TABLE 45. RECOMMENDED pH WATER QUALITY CRITERIA FOR DESIGNATED BENEFICIAL USES OF SURFACE WATERS

Water Use	Recommended Limit		Comments
Recreation & Aesthetics	6.5 - 8.3		Most Waters
	5.0 - 9.0		Poorly Buffered Waters
Public Water Supplies	5.0 - 9.0		
Aquatic Life	5.5 - 9.5	ΔpH[a] < 1.5 units	Low Level of Protection
	6.0 - 9.0	ΔpH < 1.0 units	Moderate Level of Protection
	6.0 - 9.0	ΔpH < 0.5 units	High Level of Protection
	6.5 - 8.5	ΔpH < 0.5 units	Nearly Maximum Level of Protection
Irrigation	4.5 - 9.0		Water with a pH in this range should be usable if care is taken to determine indirect harmful effects.

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[a] ΔpH Refers to changes outside the estimated natural seasonal maximum and minimum.

Source: Modified from NAS (1973).

TABLE 46. MAXIMUM RECOMMENDED LIMITS FOR ALKALINITY, ACIDITY, AND pH FOR WATER TO BE USED FOR VARIOUS INDUSTRIAL PURPOSES

	Boiler Makeup Water		Cooling Water (Fresh)		Mining Industry		Oil Recovery Injection Water
	Industrial 0 to 1500 Psig[a]	Utility 50 to 5000 Psig	Once through	Makeup Recycle	CuS Concentrator Process Water	Copper Leach Solution	Formation Water
Alkalinity ($CaCO_3$)	500	500	500	500	415	-	-
Acidity ($CaCO_3$)	1000	1000	0	200	-	-	-
pH	-	-	5.0 - 8.9	3.5 - 9.1	$\geq$ 11.7	3 - 3.5	$\geq$ 6.5

	Process Water					
	Textile Industry	Lumber Industry	Pulp & Paper Industry	Chemical Industry	Petroleum Industry	Primary Metals Industry
Alkalinity	-	-	-	500	500	200
Acidity	-	-	-	-	-	75
pH	6.0 - 8.0	5.0 - 9.0	4.6 - 9.4	5.5 - 9.0	6.0 - 9.0	3.0 - 9.0

[a] pounds per square inch gauge x 703.12 = kg/m^2.

Source: NAS (1973).

5. RECOMMENDED WATER QUALITY PARAMETERS

CHEMICAL AND PHYSICAL

It is convenient to think of water quality parameters as belonging to one of two broad categories; i.e., (1) specific constituents, or (2) indicator parameters.

The first category is comprised of those constituents which in themselves are potential pollutants and are directly measurable in waters. This group is represented by substances identified as components of raw or retorted oil shale, overburden, ground waters, industrial or urban wastes, etc., which may be subject to mobilization and release to surface waters. Examples of parameters in this group include dissolved, suspended and settleable residues, both inorganic and organic; radioactive isotopes; specific cations and anions; pesticides; and oil and grease.

The second category includes those parameters which in themselves are not pollutants, but whose measurements provide a direct or indirect measure of pollution or environmental disturbance or are required for the interpretation of other water quality data. Examples of parameters in this group include dissolved oxygen, pH, specific conductance, hardness, alkalinity, turbidity, temperature and volume of flow (discharge).

As a means of identifying and prioritizing those parameters most appropriate for monitoring, each potential pollutant addressed in Section 3 of the text was incorporated into a matrix (Table 47) and evaluated in terms of the projected impact on ambient water quality with respect to beneficial water use criteria. Also included in the matrix are those "indicator parameters" whose ambient levels are a function or product of pollution or environmental disturbance, or whose measurements are required for purposes of interpreting water quality data.

The matrix provides the mechanism for the selection and prioritization of parameters for monitoring in the following manner: Each parameter addressed in the text is listed on the Y axis under a heading corresponding to the subsection heading in which it appeared in Section 3 of the text. The X axis of the matrix is coded to seven water quality statements, any of which singly, or in combination with certain others, may describe a given parameter as it relates to ambient and projected water quality in the Colorado River System with respect to specific beneficial water-use criteria recommendations[a]. If a particular statement applies to a given parameter, a symbol keyed to a specific beneficial water use is entered in the appropriate column. Parameters described by statements 1, 2, or 3 for a particular water use are categorized as "A" priority parameters. Those described by statements 4 and 5 are "B" priority parameters, and those described by statements 6 and 7 are "C" priority parameters.

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[a] All recommendations except those for radioactive substances are based on NAS (1973). Radioactivity criteria are based on USEPA (1976b) Drinking Water Regulations.

The choices of water quality statements offered for each parameter and the code number identifying each statement used in the matrix (Table 47) are categorized by priority as follows:

Code No. Water Quality Statement

Priority "A" Parameters

1. Those parameters which have been reported in surface waters of the Colorado River Basin at levels equaling or exceeding acceptable limits with respect to beneficial water uses, and whose ambient levels in surface waters are likely to be altered by activities associated with the development and operation of an oil shale industry to the point where further impairment of beneficial water uses will result; or

2. those parameters for which water quality criteria must be established for particular receiving waters based on tolerance levels of important, sensitive species in those waters, and whose ambient levels in receiving waters are likely to be altered by activities associated with the development and operation of an oil shale industry to the point where the biota may be adversely impacted; or

3. those parameters whose measurements are essential for purposes of interpreting other water quality data.

Code No. Water Quality Statement

Priority "B" Parameters

4. Those parameters whose reported levels in the Colorado River Basin are within acceptable limits with respect to beneficial water uses, but whose ambient levels in surface water could be altered by activities associated with the development and operation of the oil shale industry to the point where impairment of beneficial water uses may result; or

5. those parameters for which no water quality criteria are established with respect to ambient levels and beneficial water uses indicated,

but the significance of the parameter in the aquatic environment is recognized and discussed, and whose ambient levels in surface waters could be altered by activities associated with the development and operation of an oil shale industry to the point where impairment of beneficial water uses may result.

Code No. Water Quality Statement

Priority "C" Parameters

6. Those parameters for which water quality criteria were not established, nor was the significance of the parameter discussed in terms of beneficial use criteria, but whose ambient levels in surface waters could be altered by activities associated with the development and operation of an oil shale industry with unknown consequences for the beneficial water uses indicated; or

7. those parameters for which adequate surface water quality data are unavailable to characterize ambient levels in the Colorado River Basin, but which have been identified as potential pollutants subject to release to surface waters by activities associated with the development and operation of an oil shale industry.

The symbols used in the matrix (Table 47) for identifying water quality criteria recommendations for beneficial water uses are as follows:

Symbol Beneficial Water Uses

I = Irrigation Agriculture
L = Livestock Drinking
D = Drinking Water (public water supplies)
W = Industrial Uses
A = Aquatic Life and Wildlife
X = Statement Applies to Parameter in Question

Physical and chemical parameters recommended for monitoring are summarized by priority category "A", "B" and "C" (Tables 48, 49, and 50). The form of each recommended parameter is based upon the available knowledge of activities and fates of pollutants in the aquatic environments.

Priority "A" parameters require intensive monitoring because: (1) very slight changes in their ambient levels would render water unacceptable for specified designated beneficial water uses; (2) changes in ambient levels would be indicative of potentially deleterious changes in water quality

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.)

		CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
Problem Category	Parameter	1	2	3	4	5	6	7
Salinity								
	Total Dissolved Solids (TDS)	I,W	A	-	L	D	-	-
	Sodium (Na)	W[a]	-	-	-	I,D,A	L	-
	Potassium (K)	W[a]	-	-	-	I,A	D,L	-
	Magnesium (Mg)	W	-	-	-	I,A	D,L	-
	Calcium (Ca)	-	-	-	W	I,A	D,L	-
	Sulfates (SO_4)	D	-	-	W	I,A	L	-
	Chlorides (Cl)	D,W	-	-	-	I,A	L	-
	Carbonates (CO_3)	-	-	-	-	A,W,D	I,L	-
	Bicarbonates (HCO_3)	W	-	-	-	I,A,D	L	-
	Silica (SIO_2)	W	-	-	-	I	D,A,L	-

[a] Numerical criteria for industrial water uses include sodium plus potassium.

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

		CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
Problem Category	Parameter	1	2	3	4	5	6	7
Salinity								
	Conductivity	I	-	-	-	-	D,A,L,W	-
	Hardness	W	-	-	-	I,D,A	L	-
Trace Elements								
	Aluminum (Al)	I,W,L	A	-	-	-	D	-
	Antimony (Sb)	-	-	-	-	-	I,L,D,W,A	X
	Arsenic (As)	-	-	-	I,L,D	-	A,W	-
	Barium (Ba)	-	-	-	D	-	I,L,W,A	-
	Beryllium (Be)	-	-	-	I	L	D,W,A	-
	Bismuth (Bi)	-	-	-	-	-	I,L,D,W,A	X
	Boron (B)	I	-	-	L	D	A,W	-
	Bromine (Br)	-	-	-	-	-	I,L,D,W,A	X
	Cadmium (Cd)	-	-	-	I,L,D,A	-	W	-

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

Problem Category	Parameter	CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
		1	2	3	4	5	6	7
Trace Elements								
	Cerium (Ce	–	–	–	–	–	I,L,D,W,A	X
	Cesium (Cs)	–	–	–	–	–	I,L,D,W,A	X
	Chromium (Cr)	–	–	–	I,L,D,A	–	W	–
	Cobalt (Co)	–	–	–	I,L	–	D,A,W	–
	Copper (Cu)	I	A	–	L,D,W	–	–	–
	Dysprosium (Dy)	–	–	–	–	–	I,L,D,W,A	X
	Erbium (Er)	–	–	–	–	–	I,L,D,W,A	X
	Europium (Eu)	–	–	–	–	–	I,L,D,W,A	X
	Fluorides (F)	I	–	–	L,D,W	–	A	–
	Gadolinium (Gd)	–	–	–	–	–	I,L,D,W,A	X
	Gallium (Ga)	–	–	–	–	–	I,L,D,W,A	–
	Germanium (Ge)	–	–	–	–	–	I,L,D,W,A	

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

		CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
Problem Category	Parameter	1	2	3	4	5	6	7
Trace Elements								
	Gold (Au)	-	-	-	-	-	I,L,D,W,A	X
	Hafnium (Hf)	-	-	-	-	-	I,L,D,W,A	X
	Holmium (Ho)	-	-	-	-	-	I,L,D,W,A	X
	Iodine (I)	-	-	-	-	-	I,L,D,W,A	X
	Iridium (Ir)	-	-	-	-	-	I,L,D,W,A	X
	Iron (Fe)	D,W	-	-	I	L	A	-
	Lanthanum (La)	-	-	-	-	-	I,L,D,W,A	X
	Lead (Pb)	D,A,	-	-	L,I	-	W	-
	Lithium (Li)	-	-	-	I	-	L,D,W,A	-
	Lutetium (Lu)	-	-	-	-	-	I,L,D,W,A	X
	Manganese (Mn)	D,W,	-	-	I	L	A	-
	Mercury (Hg)	A	-	-	L,D	-	I,W,	-

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

		CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
Problem Category	Parameter	1	2	3	4	5	6	7
Trace Elements								
	Molybdenum (Mo)	I	-	-	-	L	A,D,W	-
	Neodymium (Nd)	-	-	-	-	-	I,L,D,W,A	X
	Nickel (Ni)	I	A	-	-	-	L,D,W	-
	Niobium (Nb)	-	-	-	-	-	I,L,D,W,A	X
	Osmium (Os)	-	-	-	-	-	I,L,D,W,A	X
	Palladium (Pd)	-	-	-	-	-	I,L,D,W,A	X
	Platinum (Pt)	-	-	-	-	-	I,L,D,W,A	X
	Praseodymium (Pr)	-	-	-	-	-	I,L,D,W,A	X
	Rhenium (Re)	-	-	-	-	-	I,L,D,W,A	X
	Rhodium (Rh)	-	-	-	-	-	I,L,D,W,A	X
	Rubidium (Rb)	-	-	-	-	-	I,L,D,W,A	-
	Ruthenium (Ru)	-	-	-	-	-	I,L,D,W,A	X

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

		CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
Problem Category	Parameter	1	2	3	4	5	6	7
Trace Elements								
	Samarium (Sm)	–	–	–	–	–	I,L,D,W,A	X
	Scandium (Sc)	–	–	–	–	–	I,L,D,W,A	X
	Selenium (Se)	–	–	–	I,L,D	–	A,W	–
	Silver (Ag)	–	–	–	–	D	I,L,W,A	–
	Strontium (Sr)	–	–	–	–	–	I,L,D,W,A	X
	Tantalum (Ta)	–	–	–	–	–	I,L,D,W,A	X
	Technetium (Tc)	–	–	–	–	–	I,L,D,W,A	X
	Tellurium (Te)	–	–	–	–	–	I,L,D,W,A	X
	Terbium (Tb)	–	–	–	–	–	I,L,D,W,A	X
	Thallium (Ti)	–	–	–	–	–	I,L,D,W,A	X
	Thorium (Th)	–	–	–	–	–	I,L,D,W,A	X
	Tin (Sn)	–	–	–	–	I	L,D,W,A	–

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

		CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
Problem Category	Parameter	1	2	3	4	5	6	7
Trace Elements								
	Titanium (Ti)	–	–	–	–	I	L,D,W,A	–
	Tungsten (W)	–	–	–	–	I	L,D,W,A	X
	Uranium (U)	–	–	–	–	–	I,L,D,W,A	X
	Vanadium (V)	–	–	–	I,L	–	D,W,A	–
	Ytterbium (Yb)	–	–	–	–	–	I,L,D,W,A	X
	Yttrium (Y)	–	–	–	–	–	I,L,D,W,A	X
	Zinc (Zn)	–	A		I,L,D	–	W	–
	Zirconium (Zr)	–	–	–	–	–	I,L,D,W,A	X
Miscellaneous Toxic Substances								
	Chlorine (Cl)	–	–	–	–	–	I,L,D,W	X(A)[b]

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[b] Symbols in parentheses following X refer to those water uses for which criteria are established but ambient water quality data are lacking.

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

		CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
Problem Category	Parameter	1	2	3	4	5	6	7
Miscellaneous Toxic Substances								
	Cyanides (CN)	A		-	D	-	I,L,W	-
	Detergent builders linear alkylate sulfonates (LAS)	-	-	-		-	I,L,W	X(AD)
	Phenols	D	-	-	A	-	I,L,W	-
	Polychlorinated Biphenyls (PCB)	-	-	-	-	D	I,L,W	X(A)
	Phthalate esters	-	-	-	-	D	I,L,W	X(A)
	Pesticides[c]							
	Organochlorine	A	-	-	L,D	I	W	X
	Organophosphate	-	-	-	-	I	W	X(A,D,L)
	Miscellaneous	-	-	-	-	-	I,W	X(A,D,L)

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[c] Applies only to specific pesticides as discussed in Section 3 of the text.

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

Problem Category	Parameter	CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
		1	2	3	4	5	6	7
Nutrients								
	Nitrate - N (NO_3 - N)	D,W	-	-	L	A,I	-	-
	Nitrite - N (NO_2 - N)	-	-	-	D,L	-	A,I,W	-
	Ammonia (NH_3 - N)	A	-	-	D,W	-	L,I	-
	Kjeldahl (Kjeldahl - N)	-	-	-	-	-	I,L,D,W,A	X
	Organic (Organic - N)	-	-	-	-	-	I,L,D,W,A	X
	Total Nitrogen (Total - N)	-	-	-	-	A	L,D,W,I	-
	Total Phosphorus (P - TOT)	-	-	-	-	D,A	I,L,W	-
	Total Dissolved Phosphorus (TDP)	-	-	-	-	-	I,L,D,W,A	X

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

		CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
Problem Category	Parameter	1	2	3	4	5	6	7
Radionuclides[d,e]								
	Gross Alpha	-	-	-	D	-	-	-
	Gross Beta	-	-	-	D	-	-	-
	Cerium-144	-	-	-	-	-	D	X
	Cesium-137	-	-	-	-	-	D	-
	Plutonium-238, 239	-	-	-	-	-	D	-
	Radium-226, 228	-	-	-	D	-	-	-
	Ruthenium-106	-	-	-	-	-	D	X
	Strontium-89,90	-	-	-	D	-	-	-
	Tritium	-	-	-	D	-	-	-

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[d] U.S. EPA (1976b) Drinking water regulations for radionuclides are used rather than NAS (1973). Therefore, aquatic life, agriculture, livestock and irrigation uses are not discussed.

[e] Source: USEPA (1976a)

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

		CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
Problem Category	Parameter	1	2	3	4	5	6	7
Oil and Grease								
	Visible Oil	A,D	-	-	-	-	L,I,W	X
	Emulsified Oil	-	A	-	-	-	D,L,I,W	X
	Hexane Extractable Substances	-	-	-	-	-	D,L,I,W	X(A)
Temperature Alteration								
	Temperature	A	-	-	W	I,D	L	-
Sediments								
	Streambed Sediments	-	-	-	-	A	I,D,L,W	-
	Suspended Solids	A,W	-	-	-	I	L,D	-
	Turbidity	A	-	-	-	D	I,L,W	-
	Color	-	-	-	-	-	I,L,W	X(A,D)

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

Problem Category	Parameter	CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
		1	2	3	4	5	6	7
Hydrographic Modification								
	Water Volume	-	-	-	-	I,L,D,W,A	-	-
Oxygen								
	Dissolved oxygen (DO)	A	-	-	-	D	I,L,W	-
	Biochemical oxygen demand (BOD)	-	-	-	-	I	A,L,W,D	X
	Chemical oxygen demand (COD)	W	-	-	-	I	A,L,D	-
	Total organic carbon (TOC)	-	-	-	-	-	I,L,D,W,A	-
	Dissolved organic carbon (DOC)	-	-	-	-	-	I,L,D,W,A	X
Alkalinity								
	Alkalinity (Total)	-	-	-	A,W	D,I	L	-
	Acidity	-	-	-		A,I	D,L	X(W)

(Continued)

TABLE 47. PRIORITIZATION OF PARAMETERS FOR MONITORING THE IMPACT OF OIL SHALE DEVELOPMENT ON SURFACE WATER QUALITY (See Pages 96 to 98 for an Explanation of Code Numbers and Symbols.) (Con.)

		CODE NUMBERS						
		Priority "A"			Priority "B"		Priority "C"	
Problem Category	Parameter	1	2	3	4	5	6	7
Alkalinity								
	pH	-	-	-	I,L,A,W,D	-	-	-
	Bicarbonates (HCO_3)	W	-	-	-	I,A,D	L	-
	Carbonates (CO_3)	-	-	-	-	A,W,D	I,L	-
	Carbon dioxide (CO_2)	-	-	-	-	A	D,L,I,W	-
Interpretative Parameters								
	Water Volume	-	-	X	-	-	-	-
	Temperature	-	-	X	-	-	-	-

characteristics; or (3) data are required for the interpretation of other water quality data.

Priority "B" parameters require routine monitoring of a lower intensity than that for those parameters in the priority "A" category because slight changes in ambient levels can be tolerated without exceeding established limits for designated beneficial water uses. The measurement of parameters in this category should be in addition to those in the priority "A" category, but at reduced frequencies.

Priority "C" parameters require periodic monitoring in addition to those in the "A" and "B" categories to characterize water quality with respect to ambient levels of particular constituents and designated beneficial water uses.

BIOLOGICAL

Significance of Biological Monitoring

Biological monitoring has long been recognized as an effective tool for evaluating the stability and environmental quality of ecosystems. Biological investigations are of special significance in water quality monitoring programs because they offer a means of rapidly identifying areas affected by pollution and for assessing the degree of stress for a relatively small investment. In terms of time and money invested, biological monitoring in many situations provides one of the most efficient approaches in evaluating the nature and extent of pollution-related disturbances in aquatic ecosystems. Aquatic organisms act as natural monitors of water quality in that they respond in a measurable and predictable manner to stress induced by most types of pollution. Since the composition and structure of aquatic plant and animal communities are the result of all biological, chemical and physical interactions within the system, communities reflect the summation of all internal and external influences impacting the system including antagonistic and synergistic actions.

Macrobenthic invertebrates are particularly useful natural monitors of environmental quality in lakes and streams because of their sensitivity to changes in environmental conditions, their stationary nature, and the relative ease with which they are sampled. Since macroinvertebrates as a group are relatively immobile, they cannot seek relief from unfavorable conditions even of short duration. Consequently, the more sensitive members of a community are unable to successfully inhabit an area subjected to continuous or even intermittent pollution input or other disturbances. This results in colonization by the more tolerant or opportunistic forms, which, in the absence of competition and predation from more sensitive forms, may completely dominate the community.

Since aquatic organisms serve as continuous monitors of the environment, they sometimes provide information which is not obtained by direct measurements of water quality. Pollutants such as heavy metals and pesticides tend

TABLE 48. PRIORITY "A" CHEMICAL AND PHYSICAL PARAMETERS TO BE MEASURED IN SURFACE WATERS

Parameters	Constituent Reported	Units
Aluminum	Aluminum (Al), dissolved Aluminum (Al), total recoverable[a]	μg/liter μg/liter
Ammonia	Nitrogen Ammonia (NH_3 - N)	mg/liter
Bicarbonates	Bicarbonate ion (HCO_3)	mg/liter
Boron, dissolved	Boron (B), dissolved	μg/liter
Chlorides, dissolved	Chloride ion (Cl), dissolved	mg/liter
Conductivity	Specific Conductance	μmhos/cm at 25° C
Copper	Copper ion (Cu), dissolved Copper (Cu), total recoverable[a]	μg/liter μg/liter
Cyanides	Cyanide (CN), total recoverable	mg/liter
Fluorides	Fluoride (F), dissolved	mg/liter
Hardness	Hardness, total as $CaCO_3$	mg/liter
Iron	Iron ion (Fe), dissolved Iron (Fe), total recoverable[a]	μg/liter μg/liter
Lead	Lead ion (Pb), dissolved Lead (Pb), total recoverable[a]	μg/liter μg/liter
Magnesium	Magnesium ion (Mg), dissolved Magnesium (Mg), total recoverable	mg/liter mg/liter
Manganese	Manganese ion (Mn), dissolved Manganese (Mn), total recoverable	μg/liter μg/liter
Mercury, total	Mercury (Hg), total recoverable[a]	μg/liter
Molybdenum, dissolved	Molybdenum ion (Mo), dissolved	μg/liter

[a] To be measured in streambed sediments also (μg/kg).

(Continued)

TABLE 48. PRIORITY "A" CHEMICAL AND PHYSICAL PARAMETERS TO BE MEASURED IN SURFACE WATERS (Continued)

Parameters	Constituent Reported	Units
Nickel, dissolved	Nickel ion (Ni), dissolved	μg/liter
Nitrogen, Nitrate	Nitrate Nitrogen (NO_3 - N)	mg/liter
Oil and Grease	Visible Oil Emulsified Oils	Severity mg/liter
Oxygen	Dissolved Oxygen	mg/liter
Oxygen demand, Chemical	Chemical Oxygen demand (COD)	mg/liter
Pesticides	Organochlorine Pesticides[a,b]	μg/liter
Phenols	Phenolics	μg/liter
Potassium, dissolved	Potassium ion (K), dissolved	mg/liter
Sodium, dissolved	Sodium ion (Na), dissolved	mg/liter
Silica	Silica, dissolved (SiO_2) Silica, total (SiO_2)	mg/liter mg/liter
Solids, dissolved	Total dissolved (filtrable) residue Fixed dissolved (filtrable) residue	mg/liter mg/liter
Solids, suspended	Total suspended (non-filtrable) residue	mg/liter
	Fixed suspended (non-filtrable) residue	mg/liter
Sulfates, dissolved	Sulfate ion (SO_4), dissolved	mg/liter
Temperature	Temperature	°C
Turbidity	Turbidity	nephelometric turbidity units (NTU)

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[b] Applies to specific organochlorine pesticides as discussed in Section 3 of the text.

(Continued)

TABLE 48. PRIORITY "A" CHEMICAL AND PHYSICAL PARAMETERS TO BE MEASURED IN SURFACE WATERS (Continued)

Parameters	Constituent Reported	Units
Water Volume	Discharge	m^3/sec
Zinc	Zinc ion (Zn), dissolved	μg/liter
	Zinc (Zn), total recoverable	μg/liter

TABLE 49. PRIORITY "B" CHEMICAL AND PHYSICAL PARAMETERS TO BE MEASURED IN SURFACE WATERS

Parameters	Constituent Reported	Units
Acidity, total	Acidity, total as $CaCO_3$	mg/liter
Alkalinity, total	Alkalinity, total as $CaCO_3$	mg/liter
Alpha, gross	Total Alpha Activity	pCi/liter
Arsenic	Arsenic ion (As), dissolved	μg/liter
	Arsenic (As), total recoverable	μg/liter
Barium, dissolved	Barium ion (Ba), dissolved	μg/liter
Beryllium, dissolved	Beryllium ion (Be), dissolved	μg/liter
Beta, gross	Total Beta Activity	pCi/liter
Cadmium	Cadmium ion (Cd), dissolved	μg/liter
	Cadmium (Cd), total recoverable[a]	μg/liter
Calcium	Calcium ion (Ca), dissolved	mg/liter
	Calcium (Ca), total recoverable	mg/liter
Carbonates	Carbonate ion (CO_3)	mg/liter
Carbon dioxide	Carbon dioxide (CO_2), dissolved	μg/liter
Chromium	Chromium ion (Cr)[b], dissolved	μg/liter
	Chromium (Cr), total recoverable[a]	μg/liter
Cobalt, dissolved	Cobalt ion (Co), dissolved	μg/liter
Lithium, dissolved	Lithium ion (Li), dissolved	μg/liter
Nitrogen, Nitrite	Nitrite Nitrogen (NO_2 - N)	mg/liter
Nitrogen, total	Total Nitrogen (N)	mg/liter

[a] To be measured in streambed sediments also (μg/kg).

[b] Both trivalent and trivalent plus hexavalent forms should be measured.

(Continued)

TABLE 49. PRIORITY "B" CHEMICAL AND PHYSICAL PARAMETERS TO BE MEASURED IN SURFACE WATERS (Continued)

Parameters	Constituent Reported	Units
Oxygen demand, biochemical	Biochemical oxygen demand (BOD)	mg/liter
Pesticides	Organophosphate pesticides[a,c]	μg/liter
Phosphorus, total	Total phosphorus (P-Total)	mg/liter
Phthalate esters	Total phthalate esters	μg/liter
pH	pH	Standard Units
Polychlorinated Biphenyls	Total polychlorinated biphenyls	μg/liter
Radium 226, 228	Radium 226, 228, dissolved	pCi/liter
	Radium 226, 228, total	pCi/liter
Sediments, streambed	Streambed sediments	-
Selenium	Selenium ion (Se), dissolved	μg/liter
	Selenium (Se), total recoverable	μg/liter
Silver	Silver ion (Ag), dissolved	μg/liter
	Silver (Ag), total recoverable	μg/liter
Strontium 89, 90	Strontium 89, 90, dissolved	pCi/liter
	Strontium 89, 90, total	pCi/liter
Tin	Tin (Sn), total	μg/liter
Titanium	Titanium (Ti), total	μg/liter
Tungsten	Tungsten ion (W), dissolved	μg/liter
	Tungsten (W), total	μg/liter
Tritium	Tritium in water molecules	$Hydrogen^3$ units
	Tritium, dissolved	pCi/liter
	Tritium, total	pCi/liter
Vanadium, total	Vanadium (V), total recoverable	μg/liter

[c] Applies only to specific organophosphate pesticides as discussed in Section 3 of the text.

TABLE 50. PRIORITY "C" CHEMICAL AND PHYSICAL PARAMETERS TO BE MEASURED IN SURFACE WATERS

Parameters	Constituent Reported	Units
Antimony	Antimony ion (Sb), dissolved	mg/liter
	Antimony (Sb), total	mg/liter
Bismuth	Bismuth ion (Bi), dissolved	μg/liter
	Bismuth (Bi), total	μg/liter
Bromine	Bromine (Br)	mg/liter
	Bromide ion (Br), dissolved	mg/liter
Carbon	Organic Carbon, dissolved	mg/liter
	Organic Carbon, total	mg/liter
Cerium	Cerium ion (Ce), dissolved	μg/liter
	Cerium (Ce), total	μg/liter
Cerium 144	Cerium 144, total	pCi/liter
Cesium	Cesium ion (Cs), dissolved	μg/liter
	Cesium (Cs), total	μg/liter
Cesium 137	Cesium 137, dissolved	pCi/liter
	Cesium 137, total	pCi/liter
Chlorine	Residual chlorine (Cl), total	mg/liter
Color	True Color (Platinum Cobalt Units)	PCU
Detergent builders linear alkylate sulfonates (LAS)	LAS, total	mg/liter
Dysprosium	Dysprosium (Dy), total	μg/liter
Erbium	Erbium (Er), total	μg/liter
Europium	Europium, (Eu), total	μg/liter
Gadolinium	Gadolinium (Gd), total	μg/liter
Gallium	Gallium ion (Ga), dissolved	μg/liter
	Gallium (Ga), total	μg/liter

(Continued)

TABLE 50. PRIORITY "C" CHEMICAL AND PHYSICAL PARAMETERS TO BE MEASURED IN SURFACE WATERS (Continued)

Parameters	Constituent Reported	Units
Germanium	Germanium ion (Ge), dissolved	μg/liter
	Germanium (Ge), total	μg/liter
Gold	Gold (Au), total	μg/liter
Hafnium	Hafnium (Ha), total	μg/liter
Holmium	Holmium (Ho), total	μg/liter
Iodine	Iodine ion (I), dissolved	mg/liter
Iridium	Iridium (Ir), total	μg/liter
Lanthanum	Lanthanum ion (La), dissolved	μg/liter
	Lanthanum (La), total	μg/liter
Lutetium	Lutetium (Lu), total	μg/liter
Neodymium	Neodymium (Nd), total	μg/liter
Niobium	Niobium (Nb), total	μg/liter
Nitrogen, Kjeldahl	Kjeldahl Nitrogen, total	mg/liter
Nitrogen, Organic	Organic Nitrogen, dissolved as N	mg/liter
	Organic Nitrogen, total as N	mg/liter
Oils and Grease	Hexane Extractable Substances[a]	mg/kg
Osmium	Osmium (Os), total	μg/liter
Palladium	Palladium (Pd), total	μg/liter
Pesticides	Miscellaneous pesticides[b]	μg/liter
Phosphorus	Phosphorus, total dissolved	μg/liter

[a] To be measured in streambed sediments only.

[b] Applies only to specific pesticides as discussed in Section 3 of the text.

(Continued)

TABLE 50. PRIORITY "C" CHEMICAL AND PHYSICAL PARAMETERS TO BE MEASURED IN SURFACE WATERS (Continued)

Parameters	Constituent Reported	Units
Platinum	Platinum (Pt), total	µg/liter
Plutonium 238, 239	Plutonium 238, 239, dissolved	pCi/liter
Praseodymium	Praseodymium (Pr), total	µg/liter
Rhenium	Rhenium (Re), total	µg/liter
Rhodium	Rhodium (Rh), total	µg/liter
Rubidium	Rubidium ion (Rb), dissolved	µg/liter
	Rubidium (Rb), total	µg/liter
Ruthenium	Ruthenium (Ru), total	µg/liter
Ruthenium 106	Ruthenium 106, total	pCi/liter
Samarium	Samarium (Sm), total	µg/liter
Scandium	Scandium ion (Sc), dissolved	µg/liter
	Scandium (Sc), total	µg/liter
Strontium	Strontium ion (Sr), dissolved	µg/liter
Tantalum	Tantalum (Ta), total	µg/liter
Technetium	Technetium (Tc), total	µg/liter
Tellurium	Tellurium (Te), total	µg/liter
Terbium	Terbium (Tb), total	µg/liter
Thallium	Thallium ion (Tl), dissolved	µg/liter
	Thallium (Tl), total	µg/liter
Thorium	Thorium (Th), total	µg/liter
Uranium	Uranium ion (U), dissolved	µg/liter
	Uranium (U), total	µg/liter
Ytterbium	Ytterbium ion (Yb), dissolved	µg/liter
	Ytterbium (Yb), total	µg/liter

(Continued)

TABLE 50. PRIORITY "C" CHEMICAL AND PHYSICAL PARAMETERS TO BE MEASURED IN SURFACE WATERS (Continued)

Parameters	Constituent Reported	Units
Yttrium	Yttrium ion (Y), dissolved	µg/liter
	Yttrium (Y), total	µg/liter
Zirconium	Zirconium ion (Zr), dissolved	µg/liter
	Zirconium (Zr), total	µg/liter

to accumulate in the biota in far greater levels than are found in the water column as a result of uptake and concentration both through the food chain and directly from the water. Thus, an examination of tissue may reveal the presence of potentially hazardous substances in the biota which were not detectable in the water.

Biological monitoring should be incorporated into any monitoring program designed to assess the impact of development and operation of an oil shale industry on the freshwater ecosystem and water quality. Subtle changes in water quality characteristics may be indicated by changes in the aquatic biota before they are detected by physical-chemical monitoring procedures. Biological monitoring should not be viewed as an alternative to physical-chemical monitoring, but rather as a complementary tool for improving the efficacy of monitoring programs.

Selection of Parameters

Selection and prioritization of biological parameters were accomplished by considering both the components of the aquatic community most responsive to stress, and the measurement technique most appropriate for directly or indirectly measuring such response. The parameters were categorized and prioritized in accordance with the following criteria:

Priority "A"

(1) Measurement of those components of the aquatic community which exhibit a predictable and measurable response to the type of stress conditions anticipated considering the nature of expected pollutants and habitat alteration associated with oil shale development activities, and

(2) for which analytical and measurement techniques provide rapid and reproducible data with a minimum of monetary and manpower investments.

Priority "B"

(1) Measurement of those components of the aquatic community associated with particular habitats that may be affected by particular conditions which may be induced by development of an oil shale industry and associated activities.

Priority "A" parameters (Table 51) are recommended for routine monitoring in any basic water quality monitoring program designed to assess the environmental impact of oil shale and associated development on aquatic ecosystems. Priority "B" parameters (Table 52) should not be routinely monitored unless a specific problem is encountered or suspected in a particular environment.

TABLE 51. PRIORITY "A" BIOLOGICAL PARAMETERS

Community	Parameter	Analysis	Units
Macroinvertebrates	Counts and Identification	N[a]/Unit Substrate Area or Unit Sampling Effort (time) or Unit Sample	N/m^2 N/min N/Sample
	Biomass	Total Wt./Unit Substrate Area (ash-free) or Unit Sampling Effort	g/m^2 g/min
	Community Composition and Diversity	n[b]/Taxon S[c]/N	n/ith Taxon S/N
	Toxic Substances in Tissue	Wt. Substance/Unit Tissue Wt.	μg/g
Periphyton	Counts and Identification	N/Unit Substrate Area Diatom Species Proportional Count	N/cm^2 percent
	Biomass	Total Wt./Unit Substrate Area (ash-free)	mg/m^2
	Community Composition and Diversity	n/Taxon	n/ith Taxon
	Chlorophyll a	Wt./Substrate Area	$\mu g/cm^2$

[a] N = Total Numbers.

[b] n = Number of Individuals.

[c] S = Number of Taxa.

(Continued)

TABLE 51. PRIORITY "A" BIOLOGICAL PARAMETERS (Continued)

Community	Parameter	Analysis	Units
Fish	Counts and Identification	N/Unit Sampling Effort	N/Sample
	Biomass	Total Wt./Unit Sampling Effort (Wet Wt.)	g/Sample
	Toxic Substance in Tissue	Wt. Substance/Unit Wt. Tissue	mg/g
	Community Composition	Species List/Sample	

TABLE 52. PRIORITY "B" BIOLOGICAL PARAMETERS

Community	Parameter	Analysis	Units
Phytoplankton	Counts and Identification	N^a/Unit Volume	N/ml
	Chlorophyll a	Total Wt./Unit Volume	μg/liter
	Community Composition and Diversity	n^b/Taxon S^c/N	n/ith Taxon S/N
Fish	Flesh Tainting	Taste Test Panel	Rating Scale
	Growth Rate	Age/Length by Species	yr/mm
	Condition Factor	Length/Weight	$K = \frac{10^5 \text{ x wt(gm)}}{\text{Length (L)}^3}$
Macrophytes	Species Identification and Community Association	Areal Coverage and Community	Map of Species Association
Bacteria	Total Coliform	N/Unit Volume	N/ml
	Fecal Coliform	N/Unit Volume	N/ml

[a] N = Total Numbers.

[b] n = Number of Individuals.

[c] S = Number of Taxa.

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APPENDIX A: CONVERSION OF TEXT TABLES 1, 2, 3, 4, and 8 TO METRIC UNITS

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TABLE A-1. CONTINGENT WATER CONSUMPTION FORECASTS FOR A 1-MILLION-BARREL-PER-DAY SHALE OIL INDUSTRY (Table 1)

Requirements	Range of Water Consumption ($m^3 \times 10^6$)		
	Lower Range	Most Likely	Upper Range
Processing:			
Mining and crushing	7.4	7.4- 9.8	9.8
Retorting	11.1	11.1-14.8	14.8
Shale oil upgrading	20.9-25.9	35.7-54.2	54.2
Processed shale disposal	29.6	57.9-86.3	103.6
Power	12.3	18.5-28.3	45.6-55.5
Revegetation	0	0 -14.8	22.2
Sanitary use	1.2	1.2- 1.2	1.2
Subtotals	82.5-87.5	131.8-209.4	205.4-260.3
Associated Urban:			
Domestic use	11.1-13.5	16.0-20-9	20.9
Domestic power	0	1.2- 2.4	2.4
Subtotals	11.1-13.5	17.2-23.3	23.3
TOTALS	93.6-101	149.0-232.7	273.7-283.6
Ancillary Development:			
Nahcolite/dawsonite	-	-	39.4- 78.9
GRAND TOTALS	93.6-101	149.0-232.7	313.1-362.5

Source: Modified from USDI (1973, vol. I, p. III-44).

TABLE A-2. RANGES OF WATER USE FOR VARIOUS RATES AND METHODS OF SHALE OIL PRODUCTION ($m^3 \times 10^6$) (Table 2)

Requirements	Shale Oil Production (barrels per day)/Method of Production				
	50,000/ Underground Mine	100,000/ Surface Mine	50,000/ In Situ Mining	400,000/ Technology Mix	400,000/ Technology Mix
Processing:					
Mining and crushing	0.45 - 0.62	0.90 - 1.26		3.20 - 4.40	7.40 - 9.80
Retorting	0.71 - 0.90	1.40 - 1.80		5.00 - 6.30	11.10 - 14.80
Shale oil upgrading	1.80 - 2.70	3.60 - 5.40	1.80 - 2.70	14.40 - 21.60	35.70 - 54.30
Processed shale disposal	3.50 - 5.40	7.20 - 10.70		25.20 - 38.10	57.90 - 86.30
Power	0.90 - 1.20	1.80 - 2.50	0.90 - 2.20	7.10 - 11.30	18.50 - 28.30
Revegetation	0.00 - 0.86	0.00 - 0.86	0.00 - 0.86	0.00 - 6.00	0.00 - 14.80
Sanitary use	0.02 - 0.06	0.04 - 0.09	0.02 - 0.50	0.20 - 0.40	1.20 - 1.20
Subtotals	7.40 - 11.80	14.90 - 22.60	2.7 - 6.30	55.10 - 88.10	131.80 - 209.50
Associated Urban:					
Domestic use	0.8 - 1.1	1.4 - 1.8	0.8 - 1.0	6.6 - 8.5	16.0 - 20.9
Domestic power	0.1 - 0.1	0.1 - 0.2	0.1 - 0.1	0.6 - 0.7	1.2 - 2.4
Subtotals	0.9 - 1.2	1.5 - 2.0	0.9 - 1.1	7.2 - 9.2	17.2 - 23.3
GRAND TOTALS	8.3 - 13.0	16.4 - 24.6	3.6 - 6.9	62.3 - 97.3	149.0 - 232.8
MEAN VALUES	10.7	20.7	5.4	80.1	191.2

Source: Modified from USDI (1973, vol I, p. III-34).

TABLE A-3. SUMMARY OF STREAMFLOW RECORDS OF STREAMS DRAINING THE COLORADO OIL SHALE AREA (Table 3)

Streamflow station	Period of record	Drainage area km^2	Average discharge m^3/second	Extremes of discharge m^3/second	
				Maximum	Minimum daily
West Fork Parachute Creek near Grand Valley	Oct. 1957-Sept. 1962	124.6	0.12	4.2	0
Parachute Creek near Grand Valley	Oct. 1948-Sept. 1954 Oct. 1964-Sept. 1967	372.9	0.50	20.9	0
Parachute Creek at Grand Valley	Apr. 1921-Sept. 1927 Oct. 1948-Sept. 1954	518.0	0.86	25.8	0
Roan Creek at Simmons Ranch	June 1935-Sept. 1935 Apr. 1936-Oct. 1936 Mar. 1937-Sept. 1937	204.6	-	4.0	0
Roan Creek above Clear Creek	Oct. 1962-Sept. 1967	391.0	0.42	22.6	.03
Roan Creek near DeBeque	Apr. 1921-Sept. 1926 Oct. 1962-Sept. 1967	831.4	1.1	34.5	.09
Piceance Creek at Rio Blanco	Oct. 1952-Sept. 1957	23.3	0.04	0.65	.003
Piceance Creek near Rio Blanco	Oct. 1940-Sept. 1943	396.2	0.57	12.2	.003
Piceance Creek below Ryan Gulch	Oct. 1964-Sept. 1967	1256.1	0.35	11.3	.02
Piceance Creek at White River	Oct. 1964-Sept. 1966	1629.0	0.48	15.5	.02
Yellow Creek near White River	Oct. 1964-Sept. 1966	668.2	0.04	30.0	0

Sources: Modified from Coffin et al. (1971).

TABLE A-4. WATER REQUIRED AND PRODUCED BY TWO SINGLE MINES FOR A PROJECTED 30-YEAR PERIOD OF SHALE OIL PRODUCTION (Table 4)

Requirements[a]	Shale Oil Production (barrels per day)/Type of Mine							
	50,000/Underground Mine				100,000/Surface Mine			
	Water Requirements[b]	Water Produced[c]	Excess Water	Diverted Water	Water Requirements[b]	Water Produced[d]	Excess Water	Diverted Water
Processing:								
High quality water	0.09-0.15	0.21	0.07-0.12	0 -0.01	0.18-0.28	0.21	0.03-0.05	0.03-0.07
Low quality water	0.10-0.16	0.46	0.29-0.35		0.21-0.32	0.46	0.13-0.24	
Subtotals	0.19-0.31	0.67	0.36-0.47	0 -0.01	0.39-0.60	0.67	0.16-0.29	0.03-0.07
Associated Urban:								
High quality water	0.02-0.03			0.02-0.03				0.04-0.05
TOTALS	0.21-0.34	0.67	0.36-0.47	0.02-0.04	0.39-0.60	0.67	0.16-0.29	0.07-0.12

[a] In cubic meters x 10^6

[b] This would represent the maximum diverted surface water requirements should no water be available from processing or from the mines.

[c] Assumes a maximum pumping rate of 1.13 m^3/s declining to 0.51 m^3/s in the 30th year.

[d] Assumes a maximum initial pumping rate of 0.85 m^3/s declining to 0.51 m^3/s in the 30th year.

Source: USDI (1973, vol. I, p. III-60).

TABLE A-5. SUMMARY OF GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS IN THE PICEANCE CREEK BASIN (Table 8)

Alluvium, 0-43 meters thick; Holocene and Pleistocene (?) in age:	
Physical Character --	Sand, gravel and clay partly fill major valleys as much as 42 meters; generally less than one kilometer wide. Beds of clay may be as thick as 21 meters, generally thickest near the center of valleys. Sand and gravel contain stringers of clay near mouths of small tributaries to major streams.
Water Quality --	Near the headwaters of the major streams, dissolved-solids concentrations range from 250 to 700 mg/liter. Dominant ions in the water are generally calcium, magnesium, and bicarbonate. In most of the area, dissolved solids range from 700 to as much as 25,000 mg/liter. Above 3,000 mg/liter the dominant ions are sodium and bicarbonate.
Hydrologic Character --	Water is under artesian pressure where sand and gravel are overlain by beds of clay. Reported yields as much as 5.7 m^3/min. Well yields will decrease with time because valleys are narrow and the valley walls act as relatively impermeable boundaries. Transmissivity ranges from 75.9 m^3/day to 567.7 m^3/day. The storage coefficient averages 0.20.
Uinta Formation:	
0-381 meters thick; Eocene in age:	
Physical Character --	Intertonguing and gradational beds of sandstone, siltstone and marlstone: contains pyroclastic rocks and few conglomerate lenses. Forms surface rock over most of the area; thins appreciably westward.
Water Quality --	Water ranges from 250 to 1,800 mg/liter dissolved solids.
Hydrologic Character --	Beds of sandstone are predominantly fine grained and have low permeability. Water moves primarily

(Continued)

TABLE A-5. SUMMARY OF GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS IN THE PICEANCE CREEK BASIN (Continued)

Uinta Formation (Continued):	
Hydrologic Character -- (Continued)	through fractures. The part of the Formation higher than valley floors is mostly drained. Reported to yield as much as 0.37 m^3/min were tested in the north-central part of the basin. Formation has not been thoroughly tested, and larger yields may be possible.
Green River Formation:	
Parachute Creek Member, 152-548 meters thick; Eocene in age:	
Physical Character --	Kerogenaceous dolomitic marlstone (oil shale) and shale; contains thin pyroclastic beds, fractured to depths of at least 451 meters. Abundant saline minerals in deeper part of the basin. The member can be divided into three zones which can be correlated throughout the basin by use of geophysical logs: (1) high resistivity, (2) low resistivity or leached, and (3) Mahogany zone (oldest to youngest).
Water Quality --	Water ranges in dissolved-solids content from 250 to about 63,000 mg/liter. Below 500 mg/liter, calcium is the dominant cation: Above 500 mg/liter, sodium is generally dominant. Bicarbonate is generally the dominant anion regardless of concentration. Fluoride ranges from 0.0 to 54 mg/liter.
Hydrologic Character --	The high resistivity zone and Mahogany zone are relatively impermeable. The leached zone (middle zone) contains water in solution openings and is under sufficient artesian pressure to cause flowing wells. Transmissivity ranges from less than 33.9 m^3/day per meter, in the margins of the basin to 152 m^3/day per meter in the center of the basin. Estimated yields as much as 3.7 m^3/min. Total water in storage in the leached zone is 3,083 m^3 or more.

(Continued)

TABLE A-5. SUMMARY OF GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS IN THE PICEANCE CREEK BASIN (Continued)

Green River Formation:

Garden Gulch Member, 0-274 meters thick; Eocene in age:

Physical Character --	Papery and flaky marlstone and shale; contains some beds of oil shale and, locally, thin beds of sandstone.
Water Quality --	One water analysis indicates dissolved-solids concentration of 12,000 mg/liter.
Hydrologic Character --	Relatively impermeable and probably contains few fractures. Prevents downward movement of water. In the Parachute and Roan Creeks drainages, springs are found along contact with overlying rocks. Not known to yield water to wells.

Douglas Creek Member, 0-244 meters thick; Eocene in age:

Physical Character --	Sandstone, shale and limestone; contains oolites and ostracods.
Water Quality --	The few analytical results indicate that dissolved-solids content ranges from 3,000 to 12,000 mg/liter. Dominant ions are sodium and bicarbonate, or sodium and chloride.
Hydrologic Character --	Relatively low permeability and probably little fractured. Maximum yield is unknown, but probably less than 0.19 m^3/min.

Anvil Points Member, 0-570 meters thick; Eocene in age:

Physical Character --	Shale, sandstone, and marlstone grade within a short distance westward into the Douglas Creek, Garden Gulch, and lower part of the Parachute Creek Member. Beds of sandstone are fine grained.

(Continued)

TABLE A-5. SUMMARY OF GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS IN THE PICEANCE CREEK BASIN (Continued)

Green River Formation (Continued):	
Water Qualtiy --	The principal ions in the water are generally magnesium and sulfate. The dissolved-solids content ranges from about 1,200 to 1,800 mg/liter.
Hydrologic Character --	Sandstone beds have low permeability. A few wells tapping sandstone beds yield less than 0.03 m^3/min. Springs issuing from fractures yield as much as 0.37 m^3/min.
Wasatch Formation, 91-1525 meters thick; Eocene in age:	
Physical Character --	Clay, shale, lenticular sandstone; locally, beds of conglomerate and limestone. Beds of clay and shale are the main constituents of the formation. Contains gypsum.
Water Quality --	Gypsum contributes sulfate to both surface-water and ground water supplies.
Hydrologic Character --	Beds of clay and shale are relatively impermeable. Beds of sandstone are slightly permeable. The Formation is not known to yield water to wells.

Source: Modified from Coffin et al. (1971).

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